SURVEY OF METHODOLOGIES FOR VALUING EXTERNALITIES AND PUBLIC GOODS

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INTRODUCTION

The purpose of this report is to explain and evaluate six different methodologies for the valuation of externalities and public goods with respect to natural resources and the ecosystem. The six methodologies are: 1) general systems analysis, 2) the social fabric matrix, 3) direct cost, 4) contingent valuation, 5) travel cost, and 6) the property approach. The explanation and analysis contained in this report intends to determine their applicability to a broad definition of an ecosystem or socioecosystem.

The concept of externalities in the field of economics is essentially a concept formulated to take account of interdependence in a model based on assumptions of independence. Externalities, or external effects, is one of the characteristics used by economists to judge whether a good or service is a public good or service which should be provided by government. External effects are referred to by such names as “externalities,” neighborhood effects,” “social costs,” ”third-party effects,” “spillover effects,” and so forth. Externalities are those gains or losses which spill over onto others from the economic units initiating the economic actions. The economic units--firms or households, for example--either do not include the externalities in their decisions, or are not held accountable for them. The collective interest is at stake with regard to external effects and thus, the government is given the responsibility for such effects.

The roots of the externality concept are to be found in the work of Alfred Marshall, although his concern was not ecological. His student, A. C. Pigou, applied the externality concept to ecological problems and third parties. Later, K. William Kapp suggested that the knowledge about and extent of environmental impacts had grown to the extent that the word “externality” was no longer appropriate. He was concerned that the use of the term “externality” encouraged economic theory to continue “to treat allocation, production, exchange and distribution as if they occurred in an essentially closed and autonomous ‘economic’ sphere with only minor effects on man’s natural and social environment” [Kapp 1970:842]. Kapp suggested the term “social cost.” When he defined social cost, however, his definition was consistent with the definition of externality. He wrote, “the term social costs refers to all those harmful consequences and damages which third persons or the community sustain as a result of the productive process, and for which private entrepreneurs are not easily held accountable” [Kapp

1950:14]. A distinction between the two terms will not be maintained in this report, and they will be considered interchangeable when writing about harmful externalities.

Numerous criteria are used by economists to determine the goods and services for which the government has responsibility. Most important for this study, however, is that the U. S. Congress has authorized the government to act as guardian of the public trust with regard to natural resources. Natural resources. which include land. fish, wildlife, biota, air, water, groundwater, and drinking water supplies held in trust by the government, are to be protected by the government. This trust confers the power to collect for damages. Allowing damages for injuries to natural resources entrusted to the government is well established in the common law and in environmental statutes. Several aspects of the ecosystem entrusted to the government defy market valuation. They include facets such as: 1) microbial communities and nutrient cycling, 2) waste breakdown, 3) the role of woodlands, 4) air filtration of toxics, 5) global warming, and 6) protection of endangered species.

When discussing models and concepts whose purposes are to take into account human, social, ecological, economic, and technological system components, the words socioecosystem or socioecological will be used. Numerous words have been utilized to convey such ideas. For example. Kenyon De Greene uses the term sociotechnical to emphasize the integration of society and technology. However, socioecological or socioecosystem seem better suited because the economy and technology are part of society. The term socioecological therefore includes those two social entities and the ecology. The meaning of socioecological may best be understood as taking into account all of Figure 3 below. In this report, unless the meaning of the word “environment” is obvious, the word “ecology” or a derivative thereof will be used to denote the natural environment, so as not to confuse the meaning with the word “environment” as used in general systems analysis.

In order to evaluate the methodologies, it will be necessary to establish standards against which they can be compared. Three categories of standards which are important to consider for evaluation are standards for systems, for measurement, and for the particular public policy context under consideration. After general systems analysis is explained in Section III, its principles are used as the system standards which the other methodologies should meet in order to be considered adequate tools for modeling ecosystems or socioecosystems in a manner to allow for adequate evaluation and public policy decisions. Nine measurement standards to determine whether the methodology meets the test of developing indicators relevant to system valuation are presented in Section II. Primary criteria for natural resource and ecosystem valuation and costing-out of damages are also utilized. The aspects of each methodology which can be integrated into other methodologies will also be ascertained.

Beyond this introductory section there are seven additional sections: one devoted to measurement and indicators, five devoted to the six methodologies, and a conclusion. The six methodologies represent five different kinds, with each kind having a different purpose. Because this research is being completed to assist the Environmental Protection Agency in its task of surveying methodologies for determining valuation measures, Section II is devoted to the conceptualization of measurement in a public policy context. The nine characteristics of a good measurement indicator developed in this section are intended to serve as measurement or "Indicator Design" standards. These standards are used to evaluate each methodology along with the general systems principles from Section III. The purpose of Section III is to explain general systems analysis. While the other techniques are to be applied to perform particular tasks or achieve particular findings, general systems analysis is a body of principles which apply to all systems. Twelve of those principles will be explained in order to use them as standards for judging the other methodologies as systems tools.

Section IV is an explanation and evaluation of the social fabric matrix, which is a technical methodology to provide a tool that will integrate diverse scientific findings and diverse kinds of data bases in order to describe a system. Section V is devoted to direct cost. Section VI is used to explain and evaluate the contingent valuation and travel cost methods. Little background information is provided for these two methodologies because a number of reports devoted to them have already been completed for EPA. They are covered together in the same section because their purpose is the same. Both methodologies attempt to place a market valuation on the natural environment not included in market exchange. The final methodological section is on the property approach to the ecosystem. The property concern with regard to the ecosystem is not a methodology for doing system evaluations or natural resource valuation or restoration cost assignments. It is concerned with how to arrange and establish property institutions in order to solve externality problems.

The conclusion will summarize by comparing the different methodologies in terms of their ability to provide assistance in the valuation of externalities and public goods.

II

MEASUREMENT AS INDICATOR CREATION

Since this research is being completed to assist the Environmental Protection Agency in its task of surveying a set of methodologies for determining valuation measures, this section of the report will be devoted to the conceptualization of measurement in a public policy context. It is important to structure valuation indicators so they will serve as a relevant instrument for the public purpose intended.

As we know, research should be context specific. This rule should especially be heeded when doing policy research, and the research and measurement should be consistent with the relevant context. The context is defined by the problem. “An essential question to ask of any piece of policy research is: whose ‘problem’ is being investigated? A ‘problem’ in social science can mean one of various things” [Blumer 1982:51]. What we identify as policy problems are determined by our cultural values and societal beliefs. Thus, the values and beliefs should be consistently applied in all aspects of the design and construction of policy research and measurement. As was emphasized in the social indicator movement which began in the 1960’s, all useful measures are ultimately social. They are recognized as social indicators to indicate that they are relevant to some social context, rather than being ultimate “measures” which have universal applicability.

Kenneth Land stated that “a social indicator may be defined as a statistic of direct normative interest which facilitates concise, comprehensive, and balanced judgments . . .”[Land 1970:323]. Therefore, “the criterion for classifying a social statistic as a social indicator is its <u>informative valu</u>e which derives from its empirically verified nexus in a conceptualization of a social process” [Land 1970:323]. “Social process" should be defined broadly as was conveyed, at about the same time that Land’s criteria were written, by the interdisciplinary research group of the Water Resource Centers of the Thirteen Western States. This Technical Committee wrote that for social indicators to be completed in the area of water resources, it was necessary to have “an interdisciplinary team representing political science, geography, philosophy, ecology, economics and engineering” [Peterson 1971:1]. Their concept of “social” indicators was also broadly defined when they wrote “a social indicator is not necessarily defined according to the connotation of the word ‘social.’ . . .

Consider the case of a commonly used measure of water quality: dissolved oxygen or DO” [Peterson 1971:15]. The elements and components in a “social” system, which require the breadth of expertise envisioned by the Technical Committee in order to design and complete indicators, will be articulated later in this report. For now, it is important to recognize that policy indicators should be developed consistent with the problem, the relevant system, and the social belief criteria.

Indicator Design Standards

Therefore, to design relevant indicators, the following measurement standards need to be met.

1. Consistent with Problem: Indicators must be consistent with the needs of the sociological problem being pursued. Indicators should not be recycled data collected for other purposes.

2. Not Numerical Form: Indicators are not all in numerical form.

3. System Quantification: Mere separation of discrete objects is not the basis of numerical identity. Quantification should be designed to express a system.

4. Aggregation: Aggregation of discrete objects is not a case of measuring, but mere counting. Until a system is defined, quantification leads to indeterminate or incommensurable aggregates.

5. Limiting: Social measurement must be relative and limiting--relative to the system and expressing the limits required by all systems.

6. Systems- Characteristics: Systems principles of arrangement and order should guide numerical expression. Thus, the data system should be designed to articulate patterns, sequences, ordering, and linkages.

7. Integrated: It is important to remember that, in reality. systems are not disintegrated. Environmental conditions, institutions, and organisms exist only as a synthetic whole.

8. Non-social Entities: System specification must include physical and biological laws and their interactions along with technology.

9. Site-specific Ecology: System specification must also include conditions like soil, sea, mountains and climate--the environment in general. Thus, a social indicator system should be a geobased data system

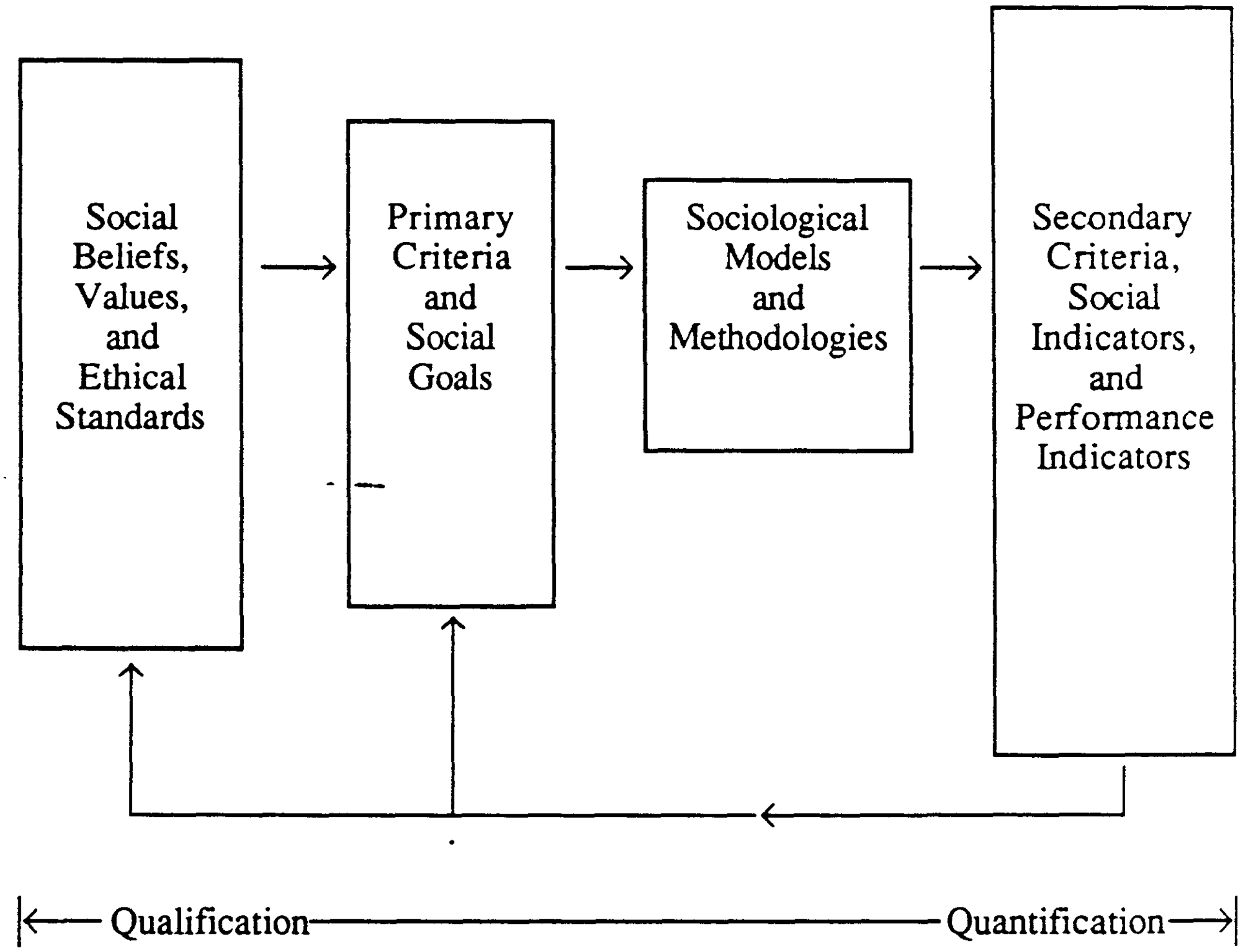
Policy Analysis Paradigm

Figure 1 is a schematic representation of a policy analysis paradigm which follows the lead of the policy scientist, Yehezkel Dror [Dror 1968 and 1986], for designing indicators which are intended to serve the purposes of public policy. Figure 1 demonstrates that social indicators are designed as the secondary criteria for the more primary criteria. The primary criteria are the social policy goals which follow from the societal beliefs, values, and ethical standards. Fact finding cannot be separated from beliefs and values. Dan McGill has emphasized this point in his book, Social Investing. He turns to distinguished ethicians and philosophers to find that "the realm of fact can neither be defined nor specified without using certain values, that it is impossible to stand firmly on the fact side of the fact-value distinction, while treating the other as vaporous, and finally, that the same processes which carve facts out of undifferentiated unconceptualized stuff also carve out the values. So it is well to look hard at the moral dimensions of decision making . . . " [McGill 1984:3-4]. Figure 1 reflects the concept of measurement as a spectrum from qualification to quantification. For example, a society with a cultural value which stresses dynamic individual action will have policy goals for good health. Thus, to assess public health programs, it is necessary to design operational measures such as the number of hospital beds per thousand of population, the change in the disease level, and so forth.

It is important, as Roland McKean clarified long ago, that the indicator be consistent with the primary goal, because operationally the indicator becomes the public policy decision criterion [McKean 1958]. It is possible conceptually to distinguish between primary and secondary criteria, but operationally it is not. The secondary criteria becomes the action criteria. A primary goal of, let's say, an efficient engine differs greatly in reality depending on whether one uses a horsepower or pollution indicator, and educational quality differs greatly depending on whether one uses an expenditure per student or a standardized test score as the indicator. In reality the policy indicators, if applied, determine the final goal. Therefore, it is important that valuation indicators for assessing the various impacts on natural resources be consistent with primary criteria and, in turn, social beliefs. This is consistent with the July 1989 opinion of the U. S. Court of Appeals, District of Columbia, which stated "'Efficiency', standing alone, simply means that the chosen policy will dictate the result that achieves the greatest value to society. Whether a particular choice is efficient depends on how the various alternatives are valued" [Ohio v. Interior 1989:456].

Figure 1 also demonstrates that the kind of indicators compiled depends on the socioecological model or methodology utilized. As Kenneth Land's quote above stipulated. an indicator derives its legitimacy as an informative tool from being empirically verified in a model. It would therefore be necessary, as indicated in Figure 1, for the models and methodologies to be consistent with the primary social criteria and goals. "The social scientist's choice of problem is given exact form when he or she

Figure 1. Policy Analysis Paradigm



comes to define and specify the concepts to be used in a particular study" [Blumer 1982:52]. As Richard B. Norgaard and John A. Dixon explain, ecological models should include both social and ecological systems [Norgaard and Dixon 1986]. Figure 1 includes a "feedback loop" from the secondary indicators back to beliefs, legal authority, and primary criteria in order to reflect that in public policymaking, the secondary indicators will feed back and provide negative or positive feedback to those entities.

Indicator concerns today are, therefore, system measures instead of just inputs and outputs. Thus, model methodologies need to be measured against the system criteria to determine their adequacy. The methodologies need to be combined in such a way as to allow for the determination of system attributes such as structure, linkages, deliveries, and control mechanisms. If there is a concern for restoration of a damaged ecosystem, for example, the functioning of those system attributes is valuable for restoration and therefore needs to be ferreted out through the methodologies. Valuation indicators can, from a system point of view, be categorized as follows:

1) <u>Consequence</u>, or impact indicators, which are designed to measure the results of policies, or damages, or ongoing system processes:

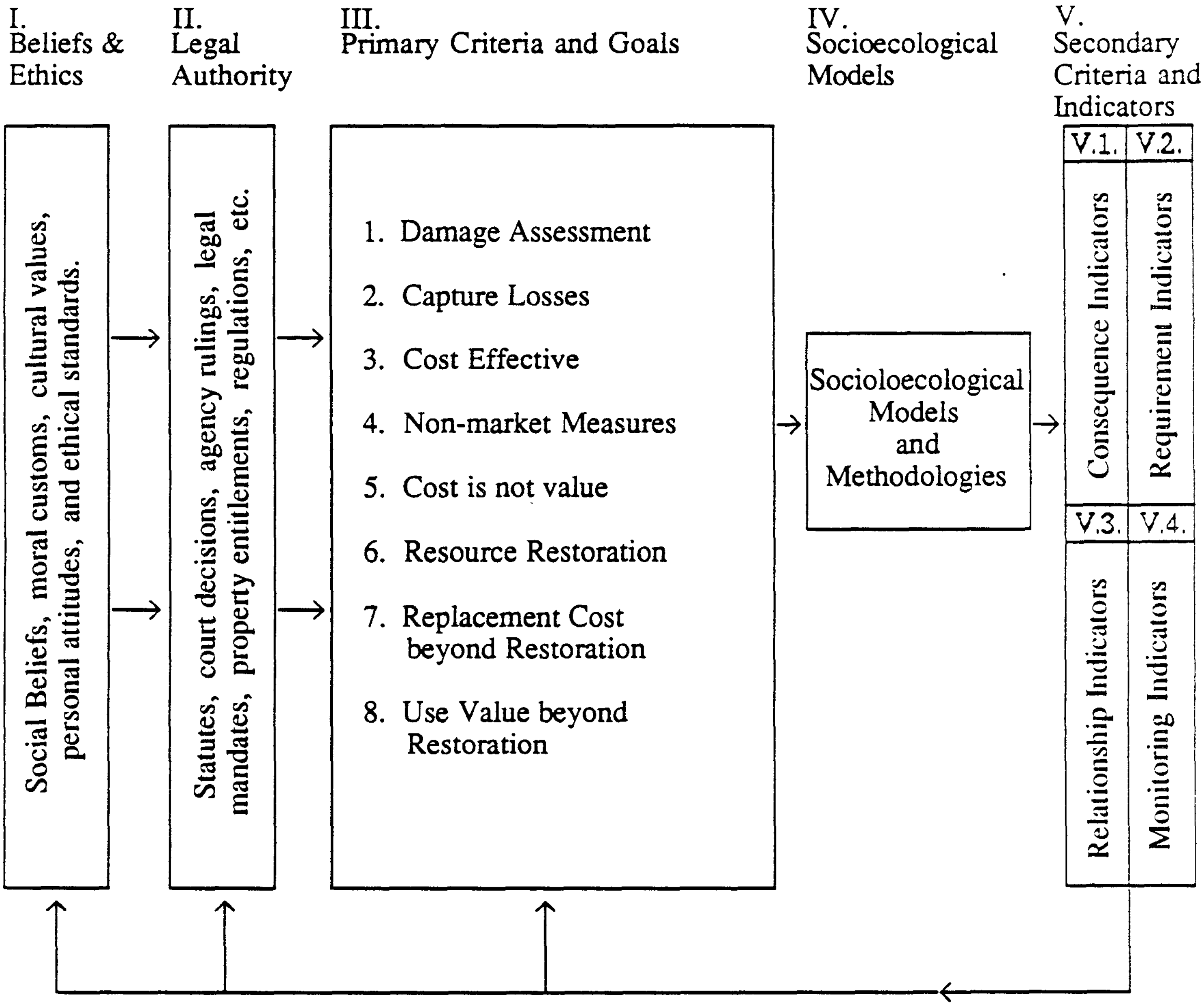
2) <u>Requirement</u> indicators, which measure the contributions to the system of the required system elements:

3) <u>Relationsh</u>ip, or linkage, indicators which measure the relationships and congruency among system elements and components:

4) <u>Monitoring</u> indicators, which are selected to provide information on some part of a system, especially after policy initiatives, to determine if system value has been maintained: for example, after restoration actions.

Figure 2 is an elaboration of Figure 1 for an application to natural resource impacts. In Figure 2, the Social Beliefs section of Figure 1 is divided into two parts. Part I is the Beliefs and Ethics section, and Part II is the Legal Authority. Legal Authority concerns have been developed consistent with social beliefs, especially as expressed by Congress, and in turn, the primary social criteria have been developed consistent with Legal Authority. A listing of primary indicators is contained in Part III of Figure 2. The purpose of this report is to survey methodologies for socioecological modeling to determine impact and valuation indicators, as displayed in Part IV. The valuation indicators which result from applied methodologies are indicated in Part V. The categories of secondary indicators in Part V will depend on the problem and the methodology being used to generate the data.

Figure 2. Policy Analysis Paradigm: Socioecological Indicators



The primary criteria listed in Figure 2, and explained below, have been developed after studying sources such as statutes, court opinions, policy statements. and scientific literature. (See for example CERCLA, SARA, and State of Ohio v. U.S. Department of the Interior.) Under the overarching goal to protect natural resources, the following primary criteria are available for defining the costs in the case of hazardous waste damage to natural resources.

1. <u>Damage Assessment:</u> To develop standardized techniques for assessing both the biological and economic damages from releases of hazardous substances.

2. <u>Capture Losses:</u> To capture fully all aspects of loss in determining damages including both direct and indirect injury. destruction, or loss, and taking into consideration factors including, but not limited to. replacement, use value, and the ability of the ecosystem or resource to recover.

3. <u>Cost-Effective:</u> To select remedial actions which provide for cost-effective actions. The required costs include the total short- and long-term costs of such actions, including the costs of operation and maintenance for the entire period during which such remedial activities are necessary.

4. <u>Non-Market Measures:</u> To employ non-market measures for the value of natural resources because natural resources have value not measured by traditional means.

5. <u>Cost is Not Value:</u> To not view market (or cost-benefit) value and restoration cost as being equal or as having equal presumptive legitimacy. Traditional means of value is not consistent with the measurement of restoration costs.

6. <u>Resource Restoration:</u> To recover all costs necessary to restore the habitat and its inhabitants to the condition they were in before the release of the hazardous substance. For example, if the spill of a hazardous substance kills a rookery of seals and destroys a habitat for seabirds at a sealife reserve, then complete restoration is the intent: to make whole the natural resources that suffered injury from release of the hazardous substance. Such damages are to include both direct and indirect injury, destruction, or loss, and are to take into consideration factors including but not limited to replacement value, use value, and ability of the ecosystem or resource to recover.

7. <u>Replacement Cost:</u> To recover replacement costs beyond restoration costs if applicable. The excess over restoration costs must be used to acquire the equivalent of the damaged resource--even though the original resource will eventually be restored. This cost is to cover whatever needs to stand in for the injured resource while restoration is under way. Flows of services provided to the public by the resource may be curtailed

long after the physical, chemical, or biological injury has abated. If a damaged forest is replanted with small trees, it will require many years before there is a mature forest.

8. <u>Use Value:</u> To recover interim use values beyond restoration if applicable. The measures of damages must not only be sufficient to cover the intended restoration or replacement uses in the usual case, but may in some cases exceed that level by incorporating interim lost use values of the damaged resources from the time of the release up to the time of restoration. Use value is to be limited to "committed use," which means a current public use or a planned public use. This avoids the need for unreliable, and likely self-serving, speculation regarding future possible uses. Option and existence values are included as use values.

To accomplish the goals elucidated by the primary criteria, numerous measures will need to be developed. As stated in EPA's Work Assignment for this project, "several aspects of wildlife habitat defy market valuation" and "information regarding the value of habitats is necessary for the agency to take full account of the impact of its regulations and other policies on the environment." [Work Assignment 1989:1]. Neither one measure nor one category of measures is sufficient to express or value system goals, nor can any one measure or concept serve as a common denominator for all the diverse indicators required.

Over the years, various groups have proposed various indicators which were to serve as the single measure or the common denominator function. These have included monetary prices, BTU's, protein ratios of the food chain, hours of leisure time, and so forth. Each of these failed to meet such an impossible standard. The failure of BTU's even as a measure of an energy system can serve as an example.

> Not all forms of energy are the same. Some forms of energy such as nuclear fission, electricity, or gasoline are quite concentrated or of high quality. These forms can perform a lot of useful work per pound or cubic foot of material. Other forms, such as sunshine, tides, wind, low temperature heat, are somewhat dilute and spread out over a large surface or volume. These forms do not have much useful work to offer, even though the total amount of energy might be the same as for a more concentrated form. Thus, in combining and evaluating the contributions of various systems, it is important that equivalent forms of energy be used. This is analogous to the old saying that we cannot add apples and pears. Likewise, we cannot add sunshine BTU's or kilocalories to gasoline BTU's or kilocalories and expect the total to accurately reflect the amount of work that can be done by that energy [Rohrlich 1979:274].

Thus, it is important for policy scientists to develop methodologies which will allow for the generation of the indicators consistent with social goals.

III

GENERAL SYSTEMS ANALYSIS

General systems analysis (GSA) is a different type of methodology than the others considered in this report. The others are techniques which are to be applied to perform particular tasks or achieve particular findings, while GSA is a body of principles which apply to all systems whether the system is social, biological, technological, ecological, or economic. GSA is a set of principles and theories with which other methodologies need to be consistent if those methodologies are to be useful in explaining and evaluating socioecological systems.

Through the years, knowledge, introspection, and experience accumulated across the disciplines and converged to find commonality among all systems. Common systems principles and characteristics, such as openness, complexity, wholeness, hierarchy, and regulation were found to be useful in explaining all systems. A. Argyal stated in 1941 that "with regard to dynamic wholes, one would expect that a given part <u>functions differently</u> depending on the whole to which it belongs. We would expect that the whole has its own characteristic dynamics" [Argyal 1941:28]. These dynamics, according to D. Katz and R. L. Kahn, can be described as systems theory. "System theory is basically concerned with problems of relationships, of structure, and of interdependency rather than with the constant attributes of objects" [Katz and Kahn 1976:90].

In some ways, attempts at systems analysis have existed at least since the time of the Greeks. We can recall that Heraclitus had systems thinking revolving around dualities such as warm and cold, black and white, day and night, life and death, pain and pleasure, being and becoming. We now know that attempts to divide a system description or evaluation into dualistic categories is naive.

The function of GSA in valuing social costs, public goods, and natural resource damages is to provide the investigator a tool kit of principles for understanding systems. The principles are to be used to describe and explain the working of socioecological systems in order to allow for the evaluation of the system and its parts as a whole. The principles are not just a descriptive nomenclature. They are theories for organizing analysis, judging methodologies, and explaining systems. To assist in understanding the relevance of GSA to the evaluation of methodologies, twelve relevant systems principles and their characteristics are defined and explained in this section.

System Defined

"A system is a set of objects together with relationships between the objects and between their attributes" [Hall and Fagen 1968:81]. Objects are the elements and components of the system. Attributes are the properties of the elements and components, and relationships are what tie the system together. The relationships to be considered "depend on the problem at hand, important or interesting relationships being included, trivial or uninteresting relationships excluded" [Hall and Fagen 1968:82]. To use De Greene's definition, "in the most general sense, a system can be thought of as being a number or set of constituents or elements in active organized interaction as a bounded entity, such as to achieve a common whole or purpose which transcends that of the constituents in isolation" [De Greene 1973:4].

There is no end to a system. Any relationship or delivery between components leads to additional deliveries, and to positive and negative feedback deliveries. One-dimensional systems (such as would be implicit in an assumption that human consumption is the end of the economic system) are not real world systems.

Openness

All real-world systems are open systems, and all open systems are non-equilibrium systems. "Open systems are those with a continuous flow of energy, information or materials from environment to system and return" [De Greene 1973:36]. There are misconceptions which arise both in theory and practice when social organizations are regarded as closed rather than open. "The major misconception is the failure to recognize fully that the organization is continually dependent upon inputs from the environment and that the inflow of materials and human energy is not a constant" [Katz and Kahn 1966:101]. Systems and their environments are open to each other, as well as subsystems within the systems being open to each other. Living systems both adapt to their environment and modify their environment.

GSA divides the analysis between the system under consideration and its environment. The system description is referred to as the internal description, or the state of the system. However, all systems are influenced by an external description which is outside the boundaries of the system. An example is the work of EPA's Environmental Monitoring and Assessment Program (EMAP). EMAP has found that a wetland ecology receives inputs such as contaminants, sediment, and nutrients from agriculture ["Environmental Monitoring . . ." 1989]. Although inputs from (often called forcings) and outputs to (often called responses) the external environment are important to the system, no attempt is made to define the environment's structure. It only has a functional "black box" description to the system. The term environment as used in systems analysis may mean an ecosystem, for example, if the system under study is a socioeconomic system. If the system of interest is an ecosystem, then the socioeconomic system is the environment. This concept is displayed in Figure 3.

In systems analysis, environment refers to the functional area outside the system. Because real world systems are constantly open to their environment, they cannot reach an equilibrium state. It is one of the goals of analysis to be able to match up the two kinds of system descriptions. "The external description is a functional one: it tells us what the system does, but not in general how it does it. The internal description, on the other hand, is a structural one: it tells us how the system does what it does . . ." [Rosen 1972:53].

Four external functions of the natural environment for the social system have been defined by D. W. Pearce in his <u>Environmental Economics</u> and refined by James A. Swaney [1987]. The functions are:

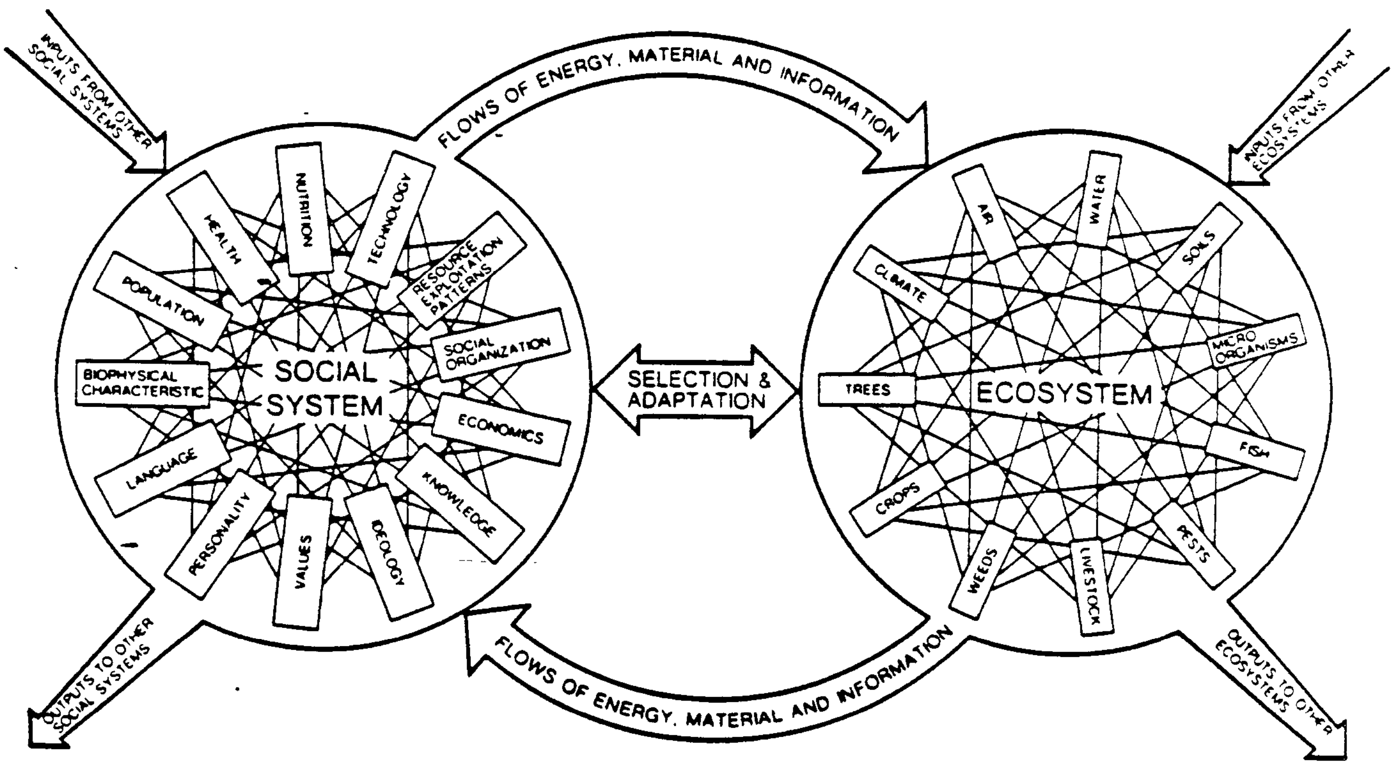
1. <u>Natural goods production,</u> which includes wilderness, greenery, landscape, scenery, and so forth. It is often competitive with natural resource production, and is restricted in quality and quantity by the production of effluents from households and production centers.

2. <u>Natural resources,</u> the raw material and energy sources flowing from the environment, upon which the production of goods and services is dependent. Natural resources represent only part of one of the two flows from the environment to the economy. They flow to the private and public production centers.

3. <u>Life support services</u> represent the services necessary for life in the environment, human communities, and work places. They include oxygen for workers in the economy and carbon dioxide that is "breathed" by farmer's fields. Life support services provided by the environment are hampered by growth in the production of economic goods. "Pearce's key point is that the life support system <u>cannot</u> be . . . priced or otherwise allocated by the economy" [Swaney 1987:337].

4. <u>The sink function</u> refers to the fact that all "wastes" from all parts of the environment and from the economy are disposed of in the environment. This sink function can no longer be taken for granted, because overloading the sinks with wastes and pollution from the households and production centers increasingly interferes with the environment's other three functions.

Figure 3. Conceptualization of Open Systems



Source: A. Terry Rambo, 1983, "Conceptual Approaches to Human Ecology." East-West Environment and Policy Institute, Research Report (June).

Nonisomorphic

Real world systems are not isomorphic from part to whole. Isomorphic systems are systems in which the whole is a reflection of the parts: for example, the sum of the parts. The idea that systems can be studied by looking at individual parts is referred to as reductionism. In living systems, the parts work according to the structure of the system. Work procedures are guided by the requirements of the technology and people's consumption is guided by social requirements. GSA allows investigators to accomplish two procedures very important to an investigation. First, it allows for abstracting the system of interest from the overwhelming complexity of the real world. Second, it provides a means of disaggregating the system into subsystems without practicing reductionism. As Rosen has explained, a reductionist hypothesis cannot be true for many of the defined properties of greatest interest about systems. [Rosen 1972:55]. The task thus is to disaggregate or fractionate a system into nonisomorphic systems so that "(a) each of the fractions, in isolation, is capable of being completely understood, and most important, that (b) any property of the original system can be reconstructed from the relevant properties of the fractional subsystems . . ." [Rosen 1972:53]. In this way, subsystem systems can be effectively utilized to give us information about the original system.

Equifinality

The equifinality property of systems means that open systems "can reach the same final state from differing initial conditions and along a variety of paths . . . "[De Greene 1973:37]. Because systems are not automatic equilibrium systems, they respond to changes in the external environment to achieve a system goal. Only by adjusting the system can open systems attain a steady state. The degree of equifinality is reduced as more control mechanisms are introduced [Katz and Kahn 1976:100]. For example, if a technology rigidly sets the requirements of the social system, the flexibility of the social system in dealing with pollution is reduced.

The concept of equifinality becomes important when determining the restoration of an ecosystem. Since there are alternative paths to achieve system viability, some paths may be less expensive in terms of resources than other paths. A technique to search for alternate paths will be discussed below.

System Components

Real world systems studies, whether they are called sociotechnical, socioenvironmental. or socioeconomic, are concerned with the integration of the components of the social, technical, and natural environmental subsystems. The components of these systems are: (1) cultural values, (2) social beliefs, (3) personal attitudes, (4) technology, (5) social institutions.

and (6) the natural environment [Hayden 1982 & 1985]. (These components will be elaborated later in the report. See pp. 24-32.)

Control and Regulation

Crucial to systems and therefore an important focus of GSA is the control and regulation mechanisms of systems. System control and regulation takes place through rules, requirements, and criteria. Two types of control are emphasized in GSA.

The first type of control is that every system element or subsystem which makes a delivery to another element or system exerts control "if its behavior is either necessary or sufficient for subsequent behavior of the other element or system (or itself), and the subsequent behavior is necessary or sufficient for the attainment of one or more of its goals" [Ackoff 1971:670]. This is a control through relationship and requirement linkages. That is why they were mentioned above in the measurement indicator section. An example is the effect of habitat cover on the kind and structure of wildlife in the habitat.

However, before elements or systems can perform the behavior pattern which gives them the first type of linkage control, other control mechanisms and rules are needed to determine their behavior. These constitute the second type of control. "Biological and social structures are not objective in the sense of physical laws. They are coherent systems obeying dynamical laws and syntactical rules that are distinguished from isolated physical systems by their ability to change their internal constraints and thereby change the rules of the game" [Pattee 1976:179].

DNA is an example of system rules which give DNA extraordinary authority over the cellular collectivity, and

> the development of multicellular organisms . . . shows that the cells do not simply aggregate to form the individual, as atoms aggregate to form crystals. There are chemical messages from the collections of cells that constrain the detailed genetic expression of individual cells that make up the collection. Although each cell began as an autonomous 'typical' unit with its own rules of replication and growth, in the collection each cell finds additional selective rules imposed on it by the collection which causes the differentiation [Pattee 1973:77].

The presence of controls and constraints in a system is a distinguishing characteristic of living systems.

Technology is another example of system rules. It provides requirements for social systems. These are often in the form of criteria which must be met. The technical component "contributes preeminently to the self-regulating features of the system" [De Greene 1973:47]. "Thus the technological system sets requirements on its social system and the effectiveness of total production will depend on how adequately the social system copes with these requirements" [De Greene 1973:47].

In social systems, primary rules are social belief criteria. They give the social system structure. "Social structure consists of myths, constraints, rules, customs, beliefs, legal codes, and the like. These structure social systems by guiding social and economic action, by legitimizing transactions, and by requiring delivery to be made" [Hayden 1986:386]. As James Swaney has clarified, in addition to the cellular, technological, and social, there are ecological constraints, rules, and criteria that we are attempting to ignore in modern real world systems [Swaney 1985]. These are also part of the system, and an attempt to override them will degrade the system.

Hierarchy

Following the discussion on system control devices, it is probably not surprising that all systems experience hierarchical arrangements of many kinds. Laszlo has defined hierarchies as "higher order systems which within their particular environments constitute systems of still more indecisive order" [Laszlo 1972:19]. Pattee emphasized the control aspects of hierarchy.

> In a control hierarchy the upper level exerts a specific dynamic constraint on the details of the motion at a lower level, so that the fast dynamics of the lower level cannot simply be averaged out. The collection of subunits that forms the upper level in a structural hierarchy now also acts as a constraint on the motions of selected individual subunits. This amounts to a <u>feedback path</u> between levels. <u>Therefore the physical behavior of a control hierarchy must take into account at least two levels at a time</u> [Pattee 1973:77; emphasis added].

The two emphases were added to Pattee's quote to emphasize criteria which technique methodologies described below will need to meet.

Flows, Deliveries, and Sequences

Systems could be defined as flows of sequenced deliveries. The concept of flow is fundamental to systems.

> Internal and external descriptions of systems are wholly complementary approaches to modeling systems structures and this equivalence can be seen through the unifying concept of flow. If a system has been described internally in terms of a number of state variables between which are defined certain

> relational functions, then these state variables can be considered to change as results of flows occurring [Bryant 1980:73].

Through input flows from the natural system into socioeconomic systems, resource analysis is completed. It is also important to explicitly include output flow to determine environmental impact assessment and valuation. “The delivery flow through the process is the substance of socioeconomic life, and is a way to measure thresholds of change. Within a system, there are tolerance levels with regard to variation of deliveries” [Hayden 1986:387].

Systems respond to flows according to the level, or amount, of the flow. It is through flow levels that systems are integrated. For example, the level of aggregate demand delivered in the economy influences the level of employment. Delivery levels outside the tolerable threshold will create negative feedback for change. For example, the food deliveries may be inadequate or the air pollution level too great.

Negative and Positive Feedback

For policy purposes, especially with regard to the natural environment, the system concept of negative and positive feedback is very important. “Negative feedback is associated with self-regulation and goal-direction, positive feedback with growth and decay” [De Greene 1973:22]. The inputs of living systems consist not only of energy and material, but also of information, all of which “furnish signals to the structure about the environment and about its own functioning in relation to the environment” [Katz and Kahn 1966:95]. Feedback is a form of inter- and intra-systemic communication in which the past performance of the system yields information to guide its present and future performance. Negative feedback systems are error-activated and goal seeking in that the goal state is compared with information inputs on the actual state and any difference (error) provides an input to direct the system toward the goal state. Negative feedback thus leads to the convergence of system behavior toward some goal [Porter 1969:5-8]. “When the system’s negative feedback stops. its steady state disappears, and the system terminates” [De Greene 1973:78]. It has been argued that one of the main benefits of democracy is the negative feedback and interference from the citizens who serve as the comparator to evaluate the condition of the system.

What makes the open systems approach so vibrant from a policy standpoint is the fact that it views the environment as being an integral part of the functioning of a sociotechnical system. Thus, external forces that affect the system need to be included in the system. Furthermore. negative feedback mechanisms are needed to provide information about environmental changes that will affect the system, in order to better understand what, if any, policies need to be made to insure a continued effective system.

Positive feedback systems, in which positive feedback information overwhelms negative feedback information, tend to be unstable since a change in the original level of the system provides an input for further change in the same direction [Porter 1969:5-8]. "Society and technology tend to reinforce one another in a positive feedback manner, which is not always desirable. At the same time there is often a loss of negative feedback and self regulation" [De Greene 1973:7]. For example, if an agricultural system based on advanced technology is not incorporating the negative information regarding soil erosion, the system will continue its growth until destruction.

Differentiation and Elaboration

"The unique character of biological and social system behavior that distinguishes them from non-living systems is their tendency to evolve greater and more significant complexity" [Pattee 1978:99]. This idea has been expressed in almost all disciplines. Katz and Kahn have stated with regard to social systems that "open systems move in the direction of differentiation and elaboration. . . . Social organizations move toward the multiplication and elaboration of roles with greater specialization of function" [Katz and Kahn 1966:99]. David Hunter and Phillip Whitten explain a similar evolution with regard to the economy. "In the economic sphere, a traditional society displays relatively little division of labor, but modern societies produce a proliferation of highly differentiated and specialized occupational statuses and roles" [Hunter and Whitten 1976:287]. Differentiation becomes an important characteristic when discussing ecological restoration. It is important to think about future differentiation potential when considering option values of an ecosystem.

Real Time

The time concept most consistent with GSA is system real time. It is inconsistent with classical ideas about time. According to the classical Kantian system, for example,

> there are the so-called forms of intuition, space and time, and the categories of the intellect, such as substance, causality and others which are universally committal for any rational being. Accordingly science based upon these categories, is equally universal. . . . Newtonian time and strict deterministic causality, is essentially classical mechanics which, therefore, is the absolute system of knowledge, applying to any phenomenon as well as to any mind as observer. It is a well-known fact that modern science has long recognized that this is not so [Von Bertalanffy 1969:226].

Moderm science applies the time concept which is most appropriate for the subject under investigation. “The biologist finds that there is no absolute space or time but that they depend on the organization of the perceiving organism” [Von Bertalanffy 1969:229]. A similar idea is found in the concept of experienced time. “Experienced time is not Newtonian. Far from flowing uniformly . . . it depends on physiological conditions” [Von Bertalanffy 1969:236].

Time is not a natural phenomenon: rather, it is a societal construct. The construct should be consistent with the GSA view and counter to the reductionist view. Time, if it is to be a useful tool in, for example, ecological restoration, should be what usually is connoted by the word timeliness. Timeliness requires that we ask the question: which restoration project will sequence and deliver the right amount of system components and elements at the right points in the ecosystem and sociotechnical system to allow for integration, maintenance, and restoration? “Temporal evaluation that judges whether a project correctly sequences the delivery of impacts with system needs is consistent with the basic concepts of computer science real time. Real time systems relate to the sequential events in a system, rather than to clock time. The system itself defines when events should happen ” [Hayden 1988:346].

Evaluation and Valuation

The EPA Work Assignment for this research project stated that methodologies should be evaluated for their contributions to the solution of the overall problem, to embrace the subtleties of the value of wildlife, to apply a broad definition of ecosystems, and to provide information regarding the value of habitats to take full account of regulations and policies on the environment. That approach to ecosystem evaluation and valuation is consistent with the GSA context. As Hall and Fagen have stated, “analysis, evaluation and synthesis of systems is not concerned primarily with the pieces . . . but with the concept of system as a whole: its internal relations, and its behavior in the given environment” [Hall and Fagen 1968:92]. The focus of evaluating and valuing is to identify the value of the various entities as they contribute toward making the socioecology viable. (See Mattessich (1978] and Laszlo [1972]). Viability includes the idea that there be redundancy in the system network and deliveries to maintain system sufficiency. Valuation assists in making decisions about the maintenance. coordination, and restoration of systems through the coordination and sequencing of relevant events.

Below the GSA principles will be used as standards by which to judge the adequacy of the other methodologies. Any methodology is adequate for some context. For example, systems of mathematical mind games can be judged to be adequate in the context of mind games. However, the task here is to judge methodological adequacy with respect to a real-world system context.

IV

SOCIAL FABRIC MATRIX

The social fabric matrix (SFM) is a technical methodology which is based on theoretical and technical developments in numerous areas. It was developed to allow for the convergence and integration of conceptual frameworks in systems analysis, boolean algebra, social system analysis, ecology, water resource planning, and geobased data systems. The focus of the SFM is to provide a tool which will integrate diverse scientific literature and diverse kinds of data bases. In this way it is possible to describe a system, articulate knowledge gaps in the system for future research, evaluate policies, opportunities, and crises within the system, and create a data base for future monitoring.

The first SFM article was published in 1982 [Hayden 1982a]. One goal of the article was to apply two principles explained by Warfield. He said, “first, there is the principle of association, which states that the developer of a model must engage in associating elements of representation systems with those things that are to be modeled. Second, there is the principle of model exchange, which states that it is desirable to find ways of transforming a model from one representation system to another to meet the needs of understanding, learning and effective communication” [Warfield: 1976:195]. This needed to be done for complex systems. For real-world modeling, “explanation often consists of substituting complex pictures for simple ones,” as Clifford Geertz stated. Thus, he added, “seek complexity and order it” [Geertz 1965:17]. This is consistent with De Greene’s advice about modeling complex systems. For him, modeling complex systems “deals with how the human, that is, behavioral and social subsystems affect and are affected by the nonhuman, that is, the technological, subsystem, and how these subsystems collectively in turn affect and are affected by the usually dynamic social and natural environments in which the larger system is enmeshed” [De Greene 1973:3].

The SFM was developed as the scientific literature indicated that a narrow conceptualization of economic systems was not viable. As ecological concerns grew, it became clear that economic systems are open systems.

> In fact, economic processes can be understood only as depending upon a continuous ‘exchange’ of energy and matter between the economy and nature. In the course of these largely

> non-market exchanges, available or economically accessible energy/matter are transformed first into inputs and then into vendible outputs and partly into residuals which will be dispersed into the atmosphere, the water, and the soil, giving rise to qualitative and quantitative changes of both the environment and the economy itself. . . . Hence economic processes have the effect of continuously altering the conditions of the environment and the economy. . . . These changes of the environment and the economy may become cumulative with far-reaching negative consequences for the conditions of human health and life, and may even endanger the conditions of economic and social reproduction in the long run [Rohrlich 1976].

Therefore, one purpose of the SFM is to take into account that the economy can neither be understood nor analyzed by a simple modeling apparatus.

A second SFM article appeared in late 1982 in which the SFM was used to organize policy research [Hayden 1982b:1013]. In addition to Albert Einstein's tremendous substantive contribution to physics, he pointed out that the results found in scientific investigations depend. even in physics, on the frame of reference and view of the investigators. This knowledge has had a pronounced impact on scientific methodology. This is true in all sciences, but it is especially true in the policy and decision sciences. Therefore, in order for research to be relevant to the problem, it is necessary to structure the policy research consistent with the decision maker's frame of reference and primary criteria. A policy research and information model can be designed which encourages researchers to ask the right questions and compile the appropriate information in order to answer them. In this way, diverse technical expertise can be harnessed into a unified system to strengthen evaluation and decision making. Thus, the context of the SFM is consistent with its use as a tool for organizing policy analysis for complex systems.

Components of the Social Fabric Matrix

Before it is possible to assemble a framework for defining the relationships contained in a problem area, it is necessary to define the components. Studies in anthropology, social psychology, economics, and ecology suggest that seven major components need to be identified and integrated. They are as follows: (1) cultural values, (2) societal beliefs, (3) personal attitudes, (4) personal tastes, (5) natural environment, (6) technology, and (7) social institutions [Hayden 1985:876]. Although, in the great majority of applied cases, cultural values can be represented by social beliefs which apply to the particular problem, the values will be defined here along with the other components.

Cultural Values

Values are a sub-set of culture. A culture is a collective systemic mental construct of the superorganic and supernatural world. It does not exist as a whole in any single mind. It contains a group's abstract ideas, ideals, and values from the superorganic and supernatural world. It is found in legends, mythology, supernatural visions, folklore, literature, elaborated superstitions, and sagas. Culture is provided by tradition and not by the human agent or social institutions. This means culture is not determined by discretionary decisions or technological change. We need to recognize that a culture is separate in definition, meaning, and performance from society. Culture, although a powerful directive and prescriptive influence on society, is cerebral while society is the set of sociotechnical relationships that direct behavior patterns. Society changes regularly but culture does not: a culture lives on even after a society is destroyed.

Cultural Values as Criteria

Values are cultural criteria or evaluative standards for judgment with regard to what is ideal. They are the ultimate criteria in the sense that they are above institutions and people. They are the focal criteria that are the locus to which all social criteria attempt to conform. For a well-adjusted society, policymakers should design sociotechnical beliefs and patterns to be in conformance with cultural values.

A problem in the social sciences regarding cultural values is that scientists attempt to extend to the analysis of values concepts which have been developed for analyzing society. For purposes of analysis and relevant policy. we need to distinguish cultural values from other entities that are sometimes referred to as values. Cultural values are not desires, motives, pleasures, beliefs, attitudes, or tastes. Neither are they determined by instrumental valuing, discretionary decision-making, nor technological change. Nor do they conform to Marxist labor theories of value. Nor can they be equated to nor measured by price. Nor are they prioritized along some hierarchical cardinal or ordinal scale. Nor can they be added up as production nor functionalized as a "social welfare function." They are criteria. The concepts mentioned in this paragraph are concepts taken from societal analysis. They are not appropriate for the analysis of cultural values.

The analysis of a group's stories, holy books, legends, and so forth reveals basic criteria common to all those sources. Those same criteria guide the group's social relationships. While the cultural values are limited in number to a dozen or so, the belief criteria guided by values number in the thousands.

Some Western cultural values that have been the same for centuries include: (1) strong domination of nature by man, (2) atomistic conceptualization, (3) extensive hierarchical relationships, (4) flowing time,

(5) dualistic thought, and (6) dynamic expansiveness. They are found in our legends, songs, religions, myths, and literature, and are acted out in our social arrangements. Although these values have been constant for centuries, they have been expressed through different societal arrangements in different eras.

When we analyze folk tales and literature, we find that our heroes and gods operate in a system consistent with the above listed cultural values. Authority and power are distributed over a wide hierarchical range. The heroes all operate in a dynamic world where the existence of growth and creation is good (how much empire taken, how many articles published), where the natural environment exists to be subdued (slaying dragons, damming raging rivers, or draining evil swamps), where good and evil are clear and dualistically structured (pleasure and pain, profit and cost), and where the faster it is all processed, the better (it is a sin to waste passing time).

Cultural values are transcendental across all aspects of culture and society. They assert themselves even in the unconscious spheres of existence. Because they are transcendental, it is impossible for the human agent or policy maker to change them in any short period of time. They are constantly being reinforced through culture, in the workplace, by movies, television, literature, linguistic structure, and so forth. Their reinforcement is direct in the culture, and indirect through beliefs in society. The values are the evaluative criteria for establishing which actions and relationships are worthy of providing satisfaction and which should be desirable. Cultural values are not goals or actions: they are end-existence criteria by which goals and actions are to be judged. They are the basic and primary prescriptive forces that circumscribe societal norms, which in turn serve as criteria for institutional patterns. Although powerful and transcendental, cultural values are not deterministic because numerous alternative beliefs and institutional arrangements can satisfy a set of criteria. They limit and exclude but do not determine.

Given the importance of values, they should be ignored least of all. This is true for at least two reasons. First, resources can be wasted if the economy is directed by trifles. Distractions such as pleasure, interest, or compulsions may misdirect energies and resources outside the spectrum of activities that culminate in patterns determined worthy by values: dissatisfaction will set in and it will be expensive to abandon concomitant economic structures. Second, a lack of concern for cultural values leads to alienation with its accompanying psychological problems, social malaise, and loss of economic productivity.

Anthropologists have found that there are cultural criteria that we need to take as given. Thus, if we have a culture with a strong emphasis on dominating nature, we cannot solve environmental problems by designing programs to live in harmony with nature. Instead we should design programs that allow us to dominate without adverse repercussions. For example, there are ways to cultivate the soil that cause high rates of soil erosion, and there are ways to cultivate it that result in building the soil. Both allow for humans to express the domination trait: however, the latter does it in a manner that serves civilization.

Social Beliefs

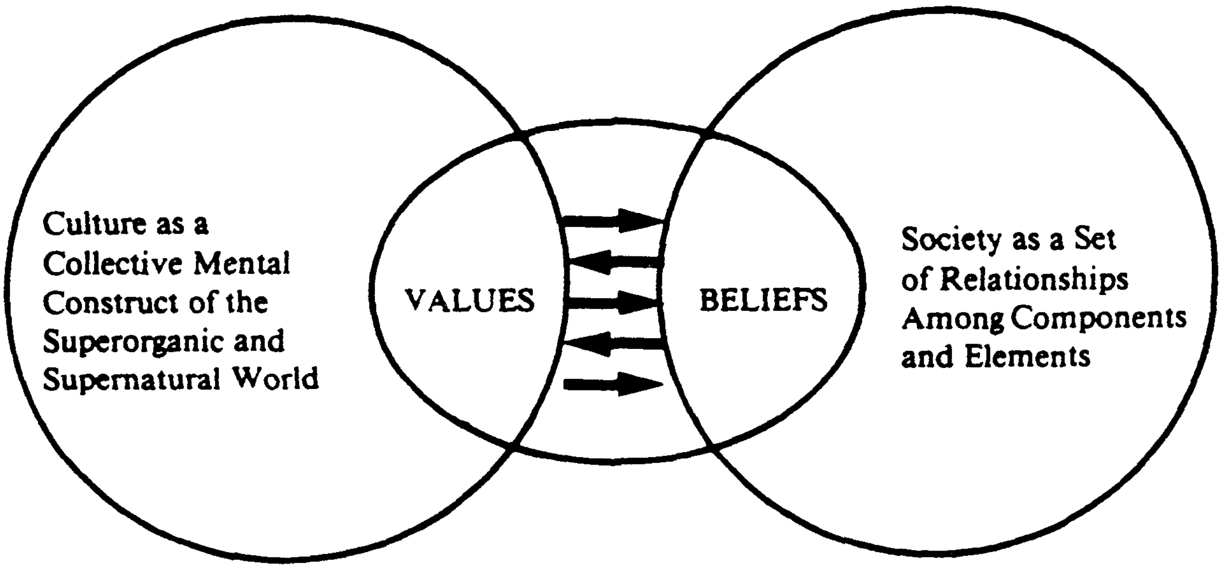
Whereas cultural values are transcendental, social beliefs are activity- and institution-specific. The connection between values and beliefs, as indicated in Figure 4, provides the bridge between culture and society. Society is a set of relationships, not people, or bronze, or horses. The relationships are determined by institutions, which are patterns of activity that prescribe the roles for the elements (humans, animals, machines, trees) as well as the emotional commitments for the human element.

As Walter Neale stated in his recent explanation of social institutions, an institution is identified by three characteristics: (1) there are patterns of activities, (2) there are rules giving the activities repetition, stability, and order, and (3) there are folkviews explaining or justifying the activities and the rules [Neale 1987). The latter are the social beliefs. The answers to the questions about why "reflect the beliefs of the participants about how and why the activities are carried on or beliefs about what justifies or ought to justify the activities" [Neale 1987].

Since institutions are accepted as normal behavior, the belief criteria justifying them are referred to as norms. These normalized beliefs are the social criteria for what is good and bad, correct or incorrect, and are, in a stable non-alienated society, in conformity with cultural values. Each institution and activity will have a cluster of beliefs that are specific to that institution. Each and every belief conforms to all cultural values. An ideology is the systematization of congruent societal beliefs. Thus, in analyzing a social or economic problem, ideological analysis is very important.

To determine system efficiency, it is necessary to consider whether institutions and economic processes fulfill cultural values and societal beliefs as outlined in the public policy paradigm above. Searching out belief criteria is an activity as varied as the institutions themselves. In a modern society, beliefs are usually expressed through codifications in statutes, court decisions, and legal opinions: and legal criteria are established for judging everything from university hiring procedures to water quality. Beyond the statutes, the agency rules, regulations, and operating procedures are where the real belief criteria are found. To find the criteria that guide business and industrial institutions, read a copy of the Standard Operating Procedure (SOP) Manual: to find labor criteria in union shops, read the union contract, and so forth. Of course a great part of the world does not have its social belief criteria so handily codified.

Figure 4. Culture and Society Related Through Values and Beliefs



Social beliefs and institutions establish roles for the elements. For each institutional situation there are obligations, permissions, and prohibitions for the elements. The human element is socialized to respond to signs and symbols in order to fulfill the responsibilities and duties of a situation. These responses are referred to as attitudes. Beliefs and institutions regulate people's attitudes toward signs and symbols and thereby regulate behavior.

Attitudes as Human Responses

Attitudes represent several social beliefs focused on a specific object or situation. It is through attitude responses that the machines are minded, the children get fed, the flags are saluted, and the trees cut. It is through attitude theory that the human actor and human action are brought into social modeling. Attitudes are held by specific people, about specific objects and situations.

After hedonism and instinct theory fell into scientific disrepute, inner drives and motives were postulated as the mechanisms from within the human that arouse, direct, and sustain activity. The Dictionary of Behavioral Science defines a motive as "a state within an organism which energizes and directs him toward a particular goal" [Wolfman 1973]. Reductionists assumed that attitudes come from the actor's motives. They assumed they could reduce to motives and then build up a social system by aggregating motives. This approach has been rejected in the psychological sciences. Time and time again attempts to study attitudes through introspection were lacking in verification [Allport 1985]. The reductionist approach has also been denied by the historical tide. The claims of utility calculation and hedonism "when tested in the crucible of social policy. proved inadequate" [Allport 1985]. The scientific reliability of motives was soon questioned even for studying hunger, thirst, and the sex drive.

With the development of social psychology, the idea that motives were operatives continued to lose credibility. The Encyclopedic Dictionary of Psychology states that "in the early days of behavioral science, motivation was envisaged in terms of the drive that was necessary for the manifestation of behavior: sexual behavior was due to the sex drive, eating to the hunger drive, etc. This is no longer a prevalent view and it is generally recognized that it is not necessary to account for behavior in terms of motive force" [Harre 1983]. Today the concern is with attitudes and the role of social institutions in determining attitudes. "Attitudes are individual mental processes which determine both the actual and potential responses of each person in the social world" [Allport 1985]. Some, especially those in psychology, are more interested in the mental processes. Economists are more interested in the responses and their origin in the social system. What are the responses to price changes? Females in the workplace? Blacks on the faculty? Safety devices in the meat packing plants? Innovations? It is the answers to these questions that articulate the economy. The attitudes operate from outside the individual, not from motives. or hedonistic urges, or utility. Social psychologist William J. McGuire, in the latest Handbook of Social Psychology, stated that "institutional structures have intended or unintended impacts on attitudes by determining the stimulus situations to which the person is exposed, the response options available, the level and type of motivation, and the scheduling of reinforcements" [McGuire 1985].

No object has meaning without reference to clustered social beliefs and attitudes. However, beliefs are determinants rather than components of attitudes. A belief in equal treatment of persons influences human attitudes and responses toward particular persons such as blacks. males, and the handicapped. "Put another way, the objects and situations we encounter have meaning for us not only because of the attitudes they activate within us but also because they are perceived to be instrumental to realization (or to stand in the way of realization) of one or more social beliefs" [Rokeach 1978]. It is through the day-to-day attitudinal responses to signs and symbols that the person-to-person, person-to-technology, and person-to-environment relationships are maintained in an institutional arrangement.

The more affluent a society in money, technology, and information, the greater the risk that members will lose sight of basic beliefs in forming their attitudes. All three lead to change and have the tendency to make society more complex, and to add additional layers of authority. Everyday activities mold attitudes, and those everyday activities may have become inconsistent with basic beliefs and values. Without effective monitoring with social indicators, human actors may also misinterpret the response that the institutional norms are conveying. In a traditional society, where the institutions are often stable over long periods, there is usually a close fit between cultural values and institutional actions. But in modern society, where institutions change rapidly, the values and goals of a society may come in conflict with institutional requirements [Wright 1975].

Since attitudes are so crucial in determining action, it is fortunate for policymaking and social planning that they can be changed without serious disruption of the social system. "Attitudes, while important and generally resistant to change, nevertheless are of less connective importance to society and easier to change than central beliefs" [Rokeach 1968]. Basic social beliefs are very difficult to change, while cultural values are unchangeable for policy purposes. The more transcendental the concept, the more social entities there are for expressing. reinforcing. and maintaining it, and thus the greater the connective importance.

Tastes as Inconsequential Attitudes

Commodity tastes are treated here as a special category of attitudes because they are related to the institution of demand. Although tastes have been given a lofty status in the tradition of economics, they are the least important of the attitude categories because they can be changed easily--usually with no impact on basic beliefs--and therefore, are without serious consequences for the belief system or the social structure. This does not mean that tastes cannot have a profound effect. For example, food tastes can have a deleterious effect on human health. The point is that those tastes can be changed without a deleterious effect on the social structure or belief system.

Values, Beliefs, and Attitudes Related to Situations

A simplified summary of the relationships described above are contained in Figure 5. Since cultural values (V_1) are transcendental, they are related to all beliefs (B_1). The values are not rank ordered. As Figure 5 indicates, basic cultural beliefs (B_1) are related to specific sub-beliefs (b_1). Particular beliefs are not related to all sub-beliefs or to all institutional activities. Clustered sub-beliefs determine attitudes (A_1). For example b_1, b_2, and b_3 provide for A_1. Within a situation the elements (T, E, S and P) respond to the objects, signs, and symbols of the situation according to response attitudes. "The argument is that person, situation, and behavior all affect each other continuously" [Allport 1985]. The elements have roles according to what they are prohibited from doing (-), permitted to do (+), and obligated to do (~). Each element would have the three roles of permission, prohibition, and obligation in each situation.

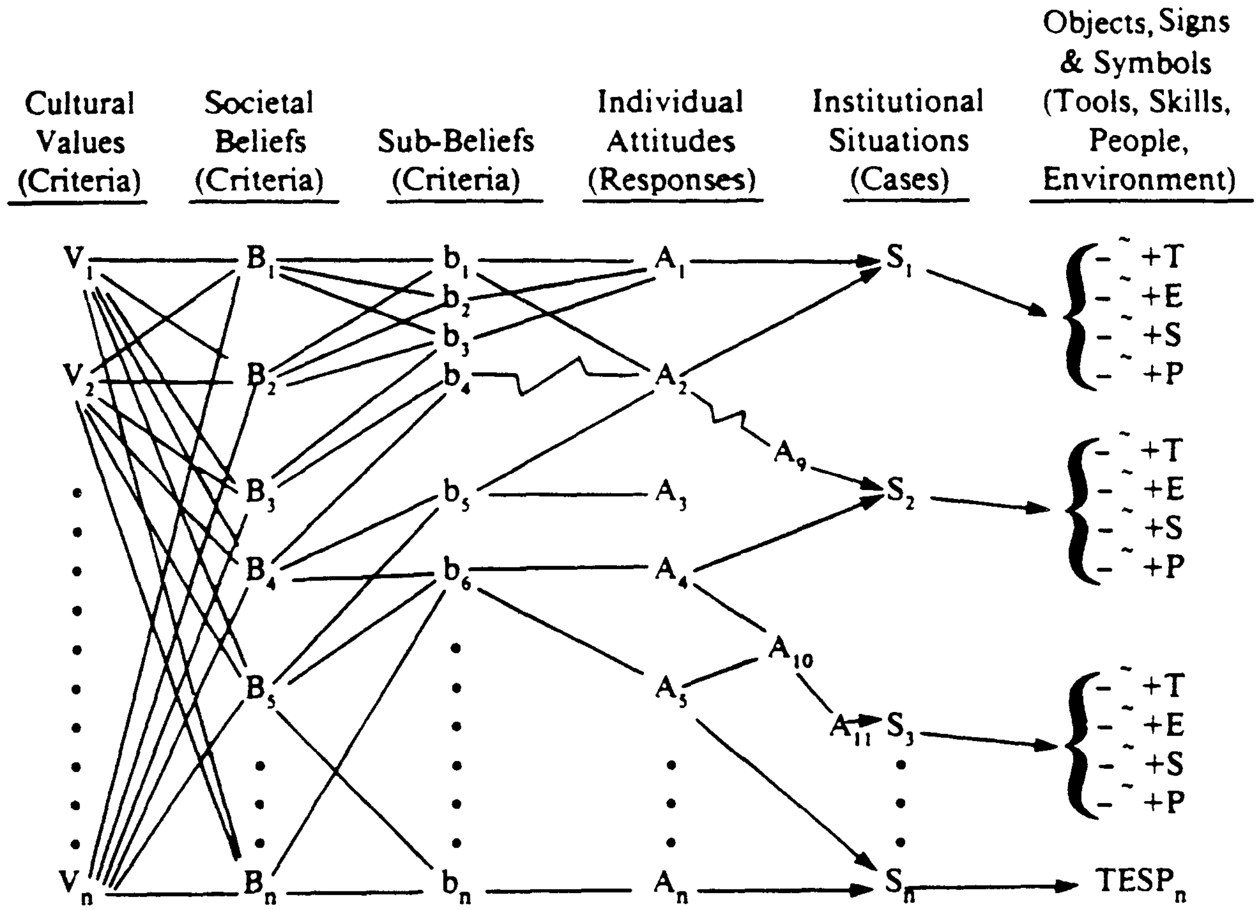
The deliveries among values, beliefs, and attitudes are demonstrated in Figure 6. Cultural values deliver criteria to beliefs and receive information from beliefs with regard to whether there is alignment between the two. Therefore, values deliver only to beliefs.

Beliefs deliver criteria to institutions. Institutions deliver social information to beliefs to determine whether the institutions are in conformance with the beliefs. This informational connection is measured by social indicators. If we look at the banking industry as an example, an array of customary, legal, and judicial belief criteria is established. The industry uses those in designing its structure, process, and procedures. The industry then provides directives to form the attitudes of its customers and employees. Finally, attitudes, as displayed in Figure 6, receive directives from institutions and provide responses, as stated above, to the elements in the institutions.

Natural Environment

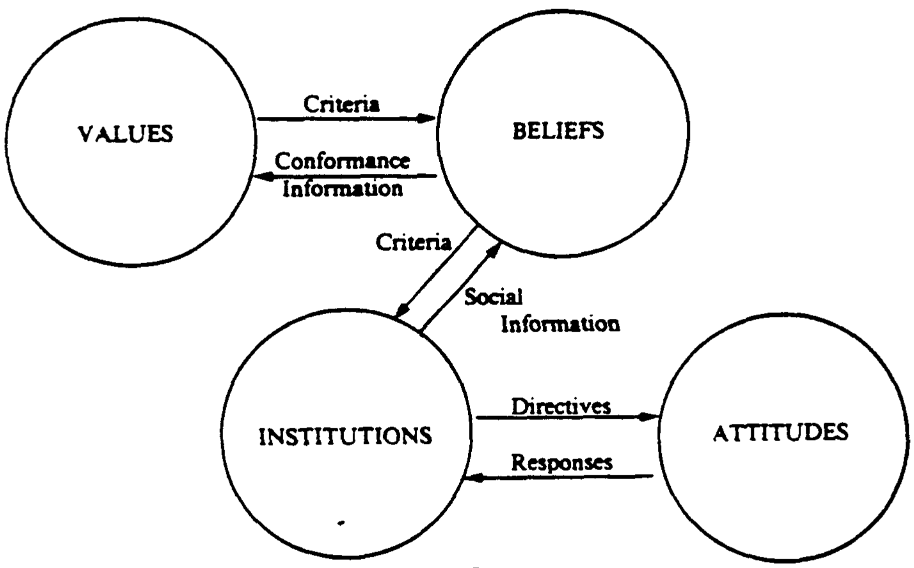
An elaborate definition of the natural environment will not be necessary here because the audience for which this report is intended is already familiar with its definition. The natural environment is probably the most difficult category to conceptualize and define as a separate component because humans, their society, and its economy and technology are so dependent on the environment as well as both flora and fauna being embedded--sometimes to extinction--in the social and technological process. The natural environment is an evolutionary whole system process.

Figure 5. Values, Beliefs, and Attitudes Related to Situations



SYMBOLS: V_i — Values, B_i — Beliefs, b_i — sub-beliefs, I_i — Institutions, A_i — Attitudes, S_i — Situations, T — Tools, E — Environmental Entities, S — Skills, P — People, —√\— —Illegitimate, + — Permission, - — Prohibition, ˜ — Obligation

Figure 6. Relationships Among Values, Beliefs, and Attitudes



This has been understood since the famous philosopher Alfred Whitehead's use of the environment as a vehicle for explaining holistic philosophy.

Technology

Technology, for the purposes here, is narrowly defined because it is useful to define it on its own and then examine how it is integrated into the whole process with regard to a particular problem. Technology is defined as tools, to include skills and intellectual tools, or knowledge. This is a much narrower meaning than when technology is defined as "organization" or as "technostructure." The purpose of the broader definitions is to emphasize the importance of technology in establishing societal, economic, and environmental patterns. The more narrow definition is used here because tools and skills are only one component. The importance of technology in a system structure is that it has a pronounced effect on production requirements, social relationships, and the environment. A change in the tool base requires a change in institutional relationships, and thus a change in beliefs. Those changes in turn change the inputs from and outputs to the natural environment.

Social Institutions

Social institutions were defined above in the section on beliefs. To summarize, they are the repetitive patterns of activity which contain the roles of the elements, provide for the structure of societal relations, and direct the flow of societal substance. They are found in society, not in culture. The prescribed and proscribed institutional roles of the elements of society are based on rules of prohibition, obligation, and permission. These rules are the norms and beliefs which evolve from and are enforced by the social process.

The components, although separated above for definitional purposes, are in fact instituted in many interdependent, transdependent, and recurrent ways.

Integration of Components

To integrate the seven components in the SFM, two principles are emphasized. One principle is the flow levels. As stated above, classical models emphasize rates and derivatives, but whole systems models emphasize the integration of flow levels. The values of flow levels are needed to fully describe societal and environmental processes. The flows of goods, services, information, and people through the network both structure and maintain regional community relationships. For example, a large regional bank, as it directs credit flows, helps structure the various communities in the region. The flow of investment to particular kinds of cultivation technology will structure the level of organic matter in the soil.

The other principle being emphasized for the SFM integration is that real- world systems depend on delivery among the component parts. Systems deliver bads and disservices as well as goods and services. Natural environments deliver floods as well as nitrogen-fixing bacteria. Factories deliver pollution as well as output. The continuity of a system depends on delivery among components according to social rules and natural principles. For example, income must be delivered to households for the continuance of the economic system, and organic residue and amino acids must be delivered to ammonia-producing bacteria for the continuance of the nitrogen cycle. Problems are created in systems when the delivery among the components is inconsistent with the maintenance of the system. Too little income delivered creates a recession, and inappropriate farming practices prevent soil bacteria from surviving.

Thus, the SFM is based upon the concept of the social components receiving from and delivering to each other. (This broadens the analytical possibilities beyond what is found with input-output, cross-interaction, and cross-impact matrices.) A process is ongoing and a system has no end. “Process suggests analysis in terms of motion” [Polanyi: 1957:250]. A delivery is used to create another delivery. Any event will perforce need to be traced through the system to find additional linkages and flows.

<u>Kind of Matrix</u>

The SFM is an integrated process matrix designed to express the attributes of the parts as well as the integrated process of the whole. The matrix process is expressed in Figure 7. The rows identified by i represent the components which are delivering, and the columns identified by j represent the components which are receiving. This is a nonequilibrium, noncommon-denominator process matrix. In this matrix, which is read from left to right, in which the ith row and the jth column are the same entry, the cell i=j defines what the ith entry (system component or element) is delivering to the jth entry, or what the jth is receiving. The terms “delivering” and “receiving” convey the basic idea that there is no final demand, absolute requirement, or end to the process. The participle form serves to denote that the process is ongoing. Process suggests analysis in terms of processing functioning.

The initial objectives in employing the matrix are to organize the scientific knowledge base, to serve as a thinking tool, and to discover components and delivery linkages not yet recognized. Thus, research begins by accumulating a broad scientific knowledge base, to include field observation, of the problem being studied. The first step after researching the problem is to construct a list of the main components, and elements of the components, which make up the real world. What one immediately finds with any problem is that many of the separately listed components affect each other. Therefore, the same list of components would be listed for the matrix rows as arranged across the columns. (See Figures 8, 12, and 14 for examples). In this way, a row component can be followed across the

Figure 7. Noncommon-Denominator Process Matrix

	j_1	j_2	. . .	j_n
i_1				
i_2				
$\vdots$				
i_n				

matrix to discover the direct columns to which it makes deliveries based on the research evidence available. Some of the deliveries will be qualitative and some quantitative: the deliveries will include criteria, court rulings, pollution emissions, goods production, services, and so forth.

At this point the SFM becomes a tool to aid thinking. As the researchers are forced to deal with each cell across the row on a cell-by-cell basis, linkages among elements will be discovered that otherwise would have been overlooked. This process helps in the discovery of research gaps, as indicated by particular matrix cells, which need to be researched. Also, the process of filling the matrix will jog the researchers' memories of new component elements to be added to the original list. They can quickly be inserted and their deliveries noted.

As a review and preview, some specific characteristics of the matrix are:

1) The matrix is based on the concept of delivery and process. A process is maintained through continuous delivery. Electric companies deliver energy, farmers deliver corn, and some industries deliver carcinogenic substances.

2) The components listed on the left are delivering to those listed across the top.

3) It is a noncommon-denominator matrix without common flow properties; for example, it can handle energy, pollution, and dollars as well as water, steel, and belief criteria. It will be necessary to develop many different kinds of numerical modalities in order to capture the essence of the various flows and relationships. This means that standard matrix algebra is not appropriate to the matrix, and that all the information in the rows and columns are not summative (as in an input-output matrix).

4) The empirical observations contained in the cells of the matrix are the flows of the system.

5) The number and kinds of entries in the matrix will depend on the problem being studied and the policymakers' interests. For example, if the problem is the economic structure of the fertilizer industry, a few broad natural environment categories are sufficient. However, if the problem is the impact of commercial fertilizer on nitrogen cycles, numerous refined environmental entries will be needed to understand the relationships of the nitrates to the micro-organism, and so forth.

6) The SFM approach defines the system as it exists; thus the concepts of equilibrium. harmony, or wants being satisfied are not forced into the system if not relevant. Toxic waste lagoons can be

delivering pollution to the water aquifer, police can be delivering arrests to individuals, and industrial processes can be delivering cancer to workers. None of them are harmonious or want satisfying, although all are part of the system.

Cellular Information

The hypothetical SFM in Figure 8 will be utilized to demonstrate some cellular information. The elements in Figure 8 are generally defined too broadly to be of more than demonstrative use. The cells are given a designation of (i, j), which means the ith row and the jth column. Explanatory comments on particular cells are as follows:

(22, 22). (22, 23) (23, 22) and (23, 23) These cells are laid out as the standard industrial input-output (I\O) matrix. Although the layout is the same, several differences exist. First, it is apparent that interindustry transactions are a minor part of the total process. As will be demonstrated next, other entities outside the I/O table must be delivered . Training must be provided from the government to the families for the delivery of skills before factories can operate. (21, 19)

(21, 22) and (21, 23) To structure industry, the government must provide the legislation.

(13, 22) and (23, 13) The forest will provide lumber as industry delivers the harvesting process to the forest.

(17, 22) Technology delivers criteria and requirements to structure the production process.

(22, 16) Industry delivers pollution to the water.

(1, 5), (1, 6), (1, 7) and (1, 8) Value criteria are delivered to beliefs.

Social institutions, technology, and environmental elements do not exist as a unified whole without the guidance and emotional commitment provided by values, beliefs, and attitudes: and in turn, values, beliefs, and attitudes cannot be expressed and therefore kept alive without a viable system which expresses them. It becomes evident that no cell is an island. Numerous cells in a sequence are processing in order to deliver a tractor to the field or health care to the public or nutrients to wildlife. That sequence has stability and dependability because of the instituted process which can be expressed in the SFM. Understanding the organization of a system requires understanding how much, how, when, and where particular ordering relationships are imposed.

Figure 8. Hypothetical Social Fabric Matrix

Receiving Components / Delivering Components		A Cultural Values A1 Dominance Over Nature 1	A2 Dynamic Expansiveness 2	A3 Bimodal Duality 3	A4 Egalitarianism 4	B Societal Beliefs (Norms) B1 Work Ethics 5	B2 Property Rights 6	B3 Affirmative Action 7	B4 Allure of Bigness 8	C Personal Attitudes C1 Soil Conservation 9	C2 Gun Procurement 10	C3 Racism 11	C4 Commodity Tastes 12	D Environment D1 Forest 13	D2 Land 14	D3 Animal 15	D4 Water 16	E Technology E1 Tool & Skill I 17	E2 Tool & Skill II 18	F Institutions F1 Kinships 19	F2 Courts 20	F3 Government 21	F4 Industry I 22	F5 Industry II 23
A Cultural Values A1 Dominance Over Nature	1					X	X	X	X															
A2 Dynamic Expansiveness	2																							
A3 Bimodal Duality	3																							
A4 Egalitarianism	4																							
B Societal Beliefs (Norms) B1 Work Ethics	5																							
B2 Property Rights	6																							
B3 Affirmative Action	7																							
B4 Allure of Bigness	8																							
C Personal Attitudes C1 Soil Conservation	9																							
C2 Gun Procurement	10																							
C3 Racism	11																							
C4 Commodity Tastes	12																							
D Environment D1 Forest	13																						X	
D2 Land	14																							
D3 Animal	15																							
D4 Water	16																							
E Technology E1 Tool & Skill I	17																						X	
E2 Tool & Skill II	18																							
F Institutions F1 Kinships	19																							
F2 Courts	20																							
F3 Government	21																		X			X	X
F4 Industry I	22																X			X			X	X
F5 Industry II	23													X									X	X

Cellular Information

Deliveries	Amount
Location	Time

System Sequence: Boolean Matrix and Diagraph

After the completion of the information in the cells, the matrix can be used to define the system sequence through boolean algebra manipulation. To convert the matrix to a sequence digraph, each cell in the matrix in which there is a delivery is labeled as 1 and each cell with no transaction is labeled as 0. This conversion of the SFM can be treated as a boolean skeleton matrix, a hypothetical example of which is displayed in Figure 9 (for the boolean algebra, see Warfield [1978] and Wilson [1972]).

The skeleton matrix can then be converted to a boolean digraph (directed graph) such as represented by the simple digraphs in Figures 10 and 11. (The digraph for Figure 9 would be much more complex.) Each node (circle) in the digraph represents a row entry in the matrix and each edge (line) represents a cell delivery. The digraphs show the sequential structure of the system. A self-contained closed system might resemble Figure 10. Figure 11 might resemble the one-directional growth model because there are no feedback loops that can be used to make decisions on the system. This kind of system has no feedback to basic beliefs; therefore, it is possible for such a system to develop inconsistent with its belief system. A one-dimensional growth system structures human relationships according to the needs of the system, which is not concerned with social beliefs and legislated policy criteria.

A simple hypothetical matrix is constructed in Figure 12 to show how the boolean process works. Assume that after research, it is found that the main elements of a problem are: (1) Farmers, (2) River, (3) Chemical Processor, (4) Goods Producer, (5) Water Aquifer, and (6) Households. These can be arranged with a 1 where there are deliveries and with a 0 where there is no delivery. The digraph for this matrix is laid out in Figure 13 with the deliveries noted on the edges. An empirical application of the SFM is Barbara Meister's "Analysis of Federal Farm Policy Using the Social Fabric Matrix" [Meister 1990]. The social fabric matrix (which is partitioned out of a larger matrix) and a partial digraph from the matrix are found in Figures 14 and 15. Some examples of Meister's matrix cells are included in Figure 16.

The digraph in Figure 13 can be used to organize further research and to collect data. Different parts of the system require different kinds of expertise, such as soil scientists. chemists, economists, water quality engineers, and so forth. Those parts can be assigned and the research people can see what kind of work needs to be done to complete the system. They will not see themselves as specialists whose work is disconnected from others. Each researcher will know with whom to coordinate and the kind of information that must be provided to other researchers. The data from the digraph can be stored in a common relational data-management spread-sheet system. Because of the importance of deliveries to a system, the delivery from component to component serves as the columnar headings

Figure 9. Boolean Skeleton Matrix

$$
\begin{array}{cc}
 & \begin{array}{ccccccccccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 \end{array} \\
\begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ 12 \\ 13 \\ 14 \\ 15 \end{array} &
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 1 & 1 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 1 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 1 & 1 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 1 & 1 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 1 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 0 \\
1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 1 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 \\
0 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\end{array}
$$

Source: John N. Warfield, Societal Systems: Planning, Policy, and Complexity (New York: John Wiley & Sons, 1976).

Figure 10. Closed Digraph

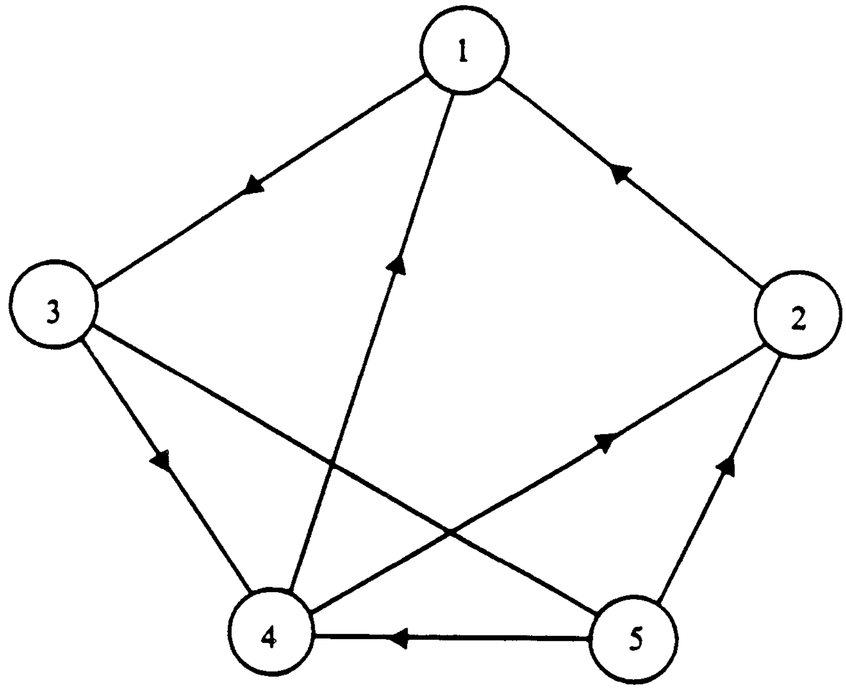


Figure 11. Unidirectional Digraph

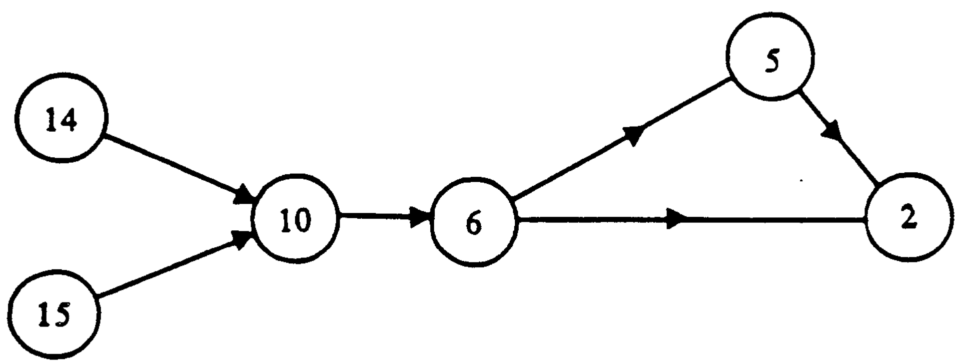


Figure 12. Simple Social Fabric Matrix

Delivery Component \ Receiving Component	Households 1	Water Aquifer 2	Goods Producer 3	Chemical Processor 4	River 5	Farmers 6
Households 1	0	0	0	0	0	0
Water Aquifer 2	1	0	0	0	0	0
Goods Producer 3	1	0	0	0	0	0
Chemical Processor 4	0	1	1	0	0	0
River 5	0	0	0	0	0	0
Farmers 6	0	0	0	1	1	0

Figure 13. Social Fabric Matrix Digraph

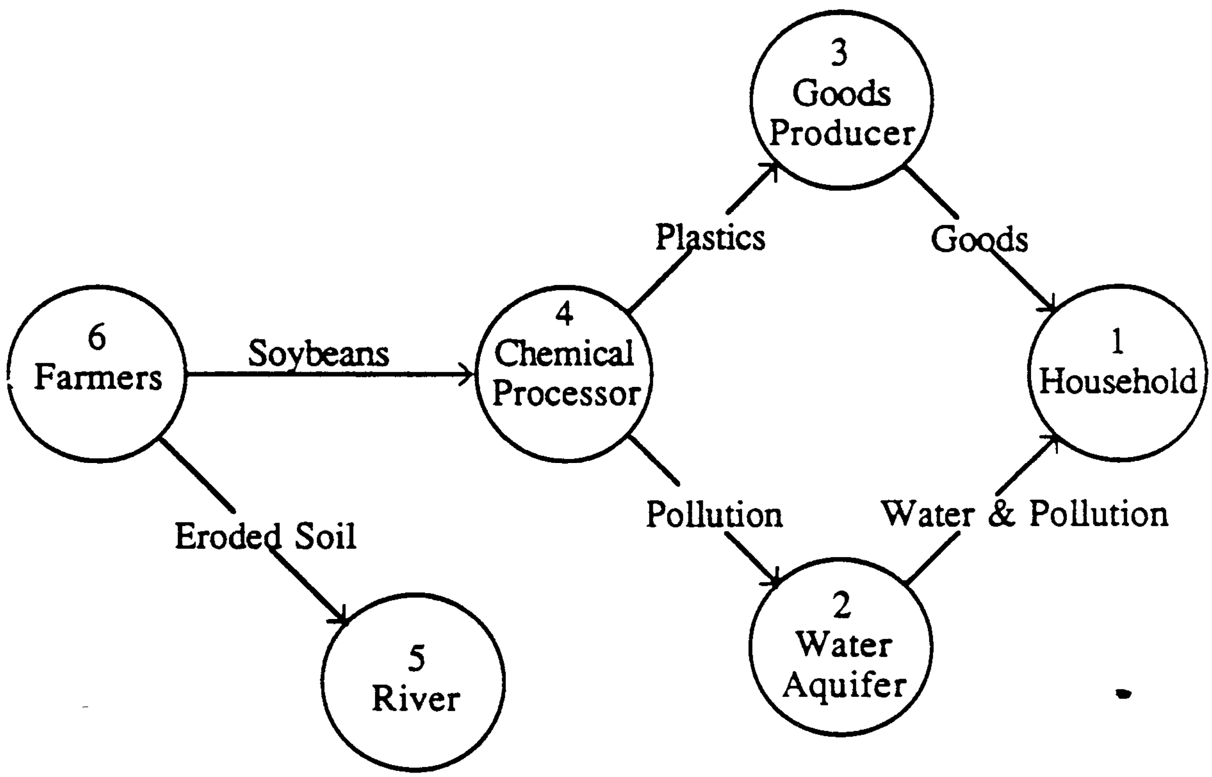


Figure 14. Farm Policy Social Fabric Matrix

		Receiving component	ATTITUDES and BELIEFS	'feed the world'	'get gov't out of agriculture'	free market	comparative advantage	U.S. dominance	INSTITUTIONS	United States	European Community	Japan	Soviet Union	Thailand	Brazil	Argentina	India	Australia	Canada	North Africa	China	China-Taiwan	South Korea	Less-developed countries	Developed countries	Centrally-planned countries	1985 Farm Bill	Export Enhancement Program	Commodity Credit Corporation	Multi-national grain companies	U.S. Farmers	U.S. Taxpayers	TECHNOLOGY	Machine technology	Chemical technology	Biotechnology	ENVIRONMENT	Rain forests	Land	Water
		B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN
1	Delivery component																																							
2	ATTITUDES and BELIEFS																																							
3	'feed the world'						X	X		X														X	X		X				X			X	X	X			X	X
4	'get gov't out of agriculture'					X				X																	X				X	X								
5	free market				X		X	X		X																	X				X									
6	comparative advantage			X				X		X																	X				X									
7	U.S. dominance			X			X			X	X																X	X			X									
8	INSTITUTIONS																																							
9	United States										X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X										
10	European Community									X																														
11	Japan									X																														
12	Soviet Union									X																														
13	Thailand									X																														
14	Brazil									X																														
15	Argentina																																							
16	India									X																														
17	Australia																																							
18	Canada																																							
19	North Africa									X																														
20	China									X																														
21	China-Taiwan									X																														
22	South Korea									X																														
23	Less-developed countries									X																														
24	Developed countries									X																														
25	Centrally-planned countries									X																														
26	1985 Farm Bill																											X	X	X									X	X
27	Export Enhancement Program																												X											
28	Commodity Credit Corporation																											X		X	X									
29	Multi-national grain companies									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X		X									
30	U.S. Farmers									X																			X	X										
31	U.S. Taxpayers																												X											
32	TECHNOLOGY																																							
33	Machine technology									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X														
34	Chemical technology									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X													X	X
35	Biotechnology									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X													X	X
36	ENVIRONMENT																																							
37	Rain forests																																							
38	Land																																							
39	Water																																							

Figure 15. SFM Digraph of U.S. Grain Trade

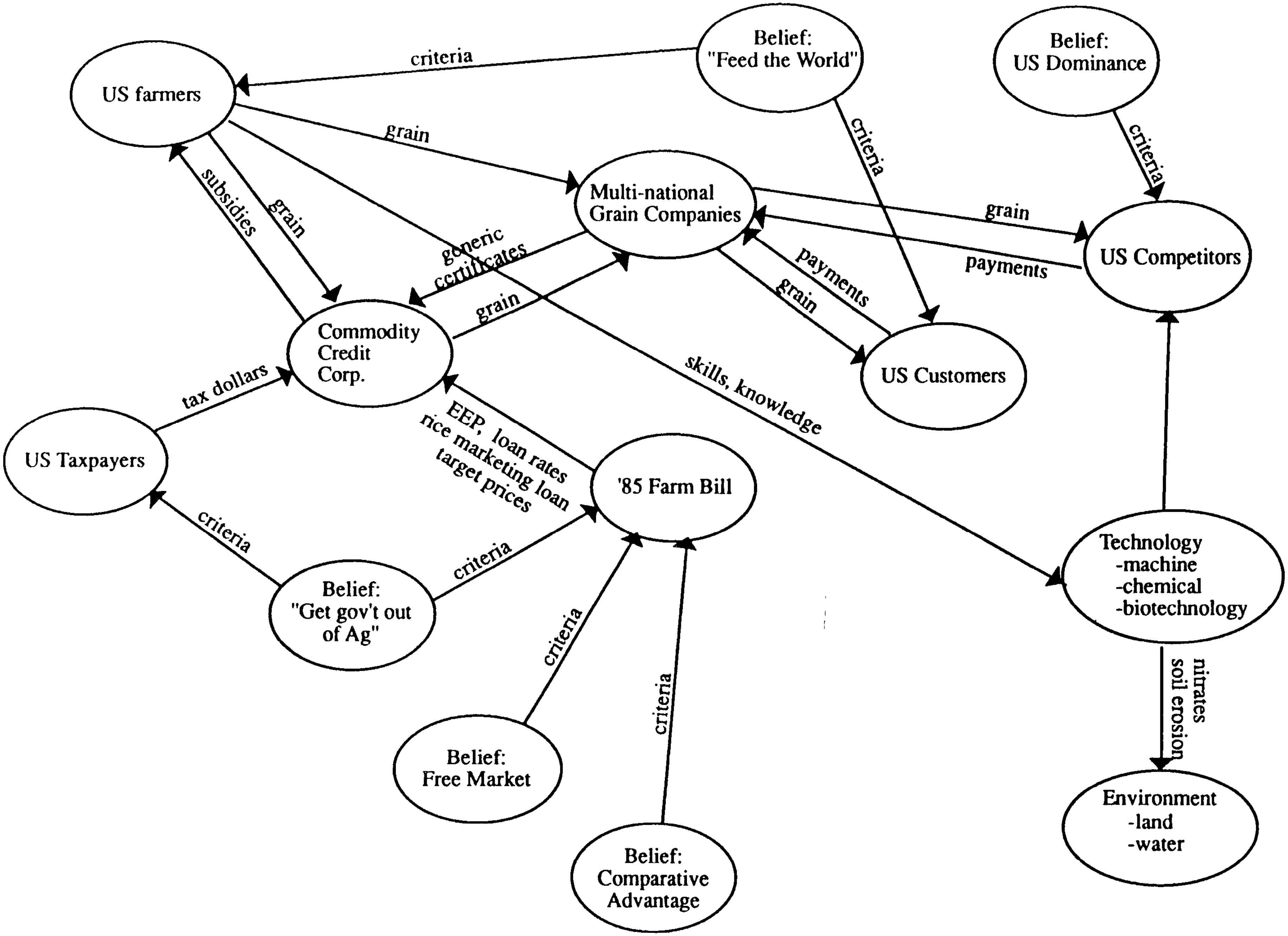


Figure 16. Farm Police Social Fabric Matrix Cells

Matrix Cell (9, X,Y,Z)

FY	(MT)
78/79	2,396,186
79/80	2,954,701
80/81	3,171,812
81/82	2,911,269
82/83	2,275,543
83/84	2,293,021
84/85	1,971,578
85/86	2,382,246
86/87	2,453,972
87/88	2,172,811

Rice delivered from US to wheat importing nations

Matrix Cell (19,AD)

Date	Dollars/ton f.o.b
21-Jan	$113.00
21-Jan	$113.50
23-Jan	$106.50
23-Jan	$106.00
30-Apr	$91.00
30-Apr	$87.00
30-Apr	$86.00
2-May	$91.00
14-May	$88.00
9-Dec	$64.75
9-Dec	$63.00
9-Dec	$63.00

Payments from Morocco to grain traders

Matrix Cell (28,AD)

Date	Dollars/ton
21-Jan	$22.81
21-Jan	$22.81
23-Jan	$25.38
23-Jan	$24.95
30-Apr	$40.10
30-Apr	$40.10
30-Apr	$40.10
2-May	$46.39
14-May	$38.40
9-Dec	$44.60
9-Dec	$44.60
9-Dec	$43.69

Subsidies from CCC to grain traders

Figure 17. Data Management Spread Sheet

Years	Soybeans 6⟶4	Eroded Soils 6⟶5	Plastics 4⟶3	Pollution 4⟶2	Goods 3⟶1	Water & Pollution 2⟶1

in such data systems, as in Figure 17. The headings in Figure 17 are taken from Figure 12.

The relationships among the various deliveries can, through this kind of research power, be discovered and built into the digraphs and spreadsheets so that if a policy change is made in one part of the system, the impacts on other deliveries would be indicated. In this way, indirect impacts from policies can be identified along with the direct ones as alternative policy scenarios are developed. For budgeting purposes, it also allows the determination of results per dollar spent on programs. The columns of the spreadsheet can be added for different programs and those totals compared to the budgets of the different programs.

The digraphs by themselves are very useful for conveying to the research group the structure of the system. In addition, they allow for quick identification of gaps. If the digraph is not fully connected, then it is not fully defined and must be more fully articulated. As the research team makes changes in either the digraph or matrix, the computer will automatically translate the change to the other. In addition, graph theory has been developed which will allow digraphs to be used as analytical tools themselves. The degree of isomorphism of alternative digraphs can be measured so that the difference between current systems and desired systems can be ascertained. Boolean techniques also exist for comparing the capacity of various parts of the system to determine where shortages and surpluses will develop. The surplus may, for example, be excess hazardous waste.

Instead of thinking just in terms of introducing policy changes, environmental accidents can be introduced into the matrix to determine the direct and indirect deliveries that take place throughout the matrix and digraph.

When it is possible to trace the sequences and linkages in a system, problems and their policy solutions appear much different. For example, there is a global interest in the wetlands located in the state of Nebraska because they are used as a staging area for migrating birds from Russia, Northern Europe, Canada, and Mexico. As farmers have continued to drain the wetlands, it has severely impacted the bird population. The assumption has been that the farmers convert wetlands to farmland for profit. It was assumed that the condition of the wetlands was an externality exogenous to the farmers' profit-maximizing mode of thinking. Thus the policy advice for saving wetlands was a pecuniary solution of offering payments to farmers for not converting the wetlands. This policy has not been successful. Analysis found in fact that draining the wetlands was not external to the farmers' decision process. Altering their condition was primary. When the work of social psychologists was consulted, it was found that an important determinant of the farmers' decisions was their belief in the domination of land and in the destruction of wildlife habitat irrespective of whether it was profitable. The belief system in conjunction with the increased availability of drainage technology is responsible for the drainage [Swanson et al., 1982]. Thus, a more complete analysis which includes all the relevant elements can be used for more relevant policy alternatives.

Comparison to GSA Principles

The next task will be to compare the SFM methodology to the twelve GSA principles and characteristics explained above. Digraphs will be used to explain the extent of the SFM's congruence with GSA principles rather than using matrices. However, the reader should be aware of two points. First, that digraphs do not exist separate from the boolean matrices. Any manipulation, optimization, or partitioning of the system must be done through the skeleton matrix. Second, that digraphs, although helpful in providing a visual aid in understanding a system and organizing its analysis, can also mislead. Without a matrix test which indicates the antecedents and succedents, the three digraph maps in Figure 18 might create a very different perception. In fact, they are the same map.

1. System defined

The SFM approach is consistent with the definition of systems concepts. It defines a whole that transcends the constituents. It defines the components, it allows for the integration of scientific findings, field observations, and data bases, and it provides a set of elements together with a definition of the relationships among the elements.

GSA clarifies that there is no end to a system. The SFM digraph allows investigators to see if they have constructed such a system. For example, in Figure 19 (below), node 1 appears as the end of the system. To see such a digraph would indicate to investigators that the system is not fully articulated.

The SFM approach also encourages the development of the rich and subtle complexity of the system while providing boolean mathematical techniques and graph theory to order the complexity for analysis and data-base development

2. Openness

Figure 19 is used to illustrate that the SFM approach is an open system approach. The matrix and digraph contain the information on the flow of energy, information, and material. Figure 19 illustrates three different types of systems. At the top of Figure 19, designated by Roman numeral nodes, is a decentralized balanced system. However, it is open because V delivers to node 8, which is external to the system. In the middle of Figure 19 is a unidirectional system designated by Arabic numeral nodes, and at the bottom is a system designated by the English alphabet, which is a

Figure 18. Three Maps of the Same Digraph

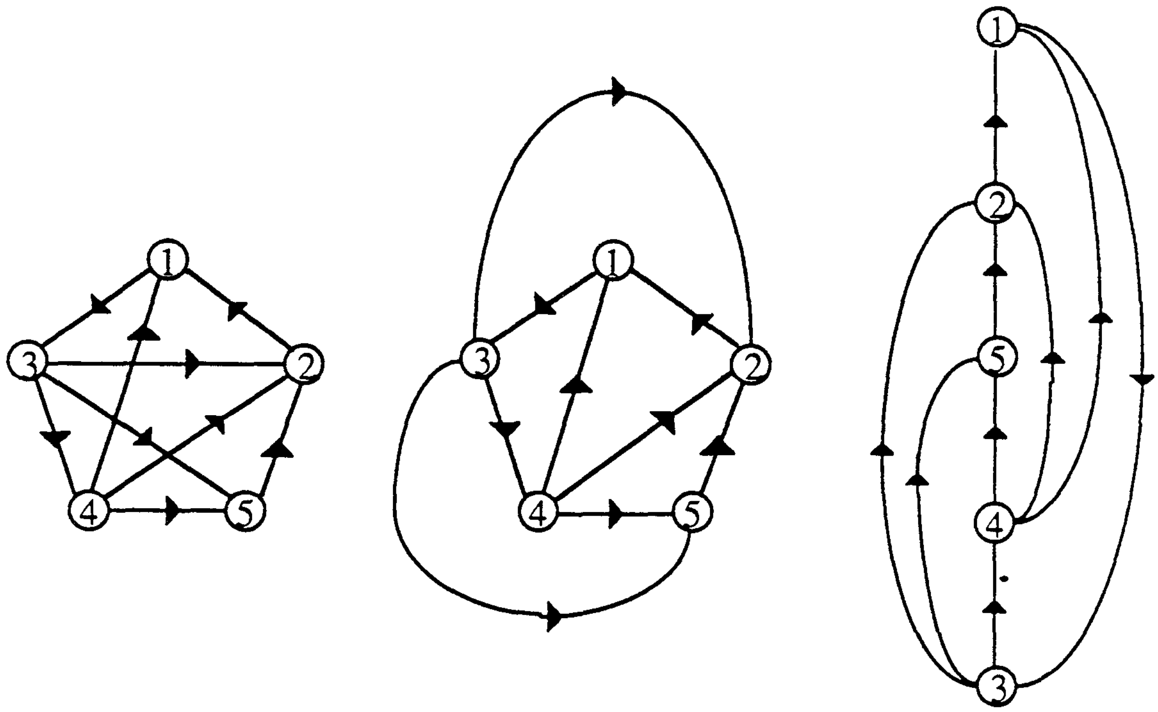
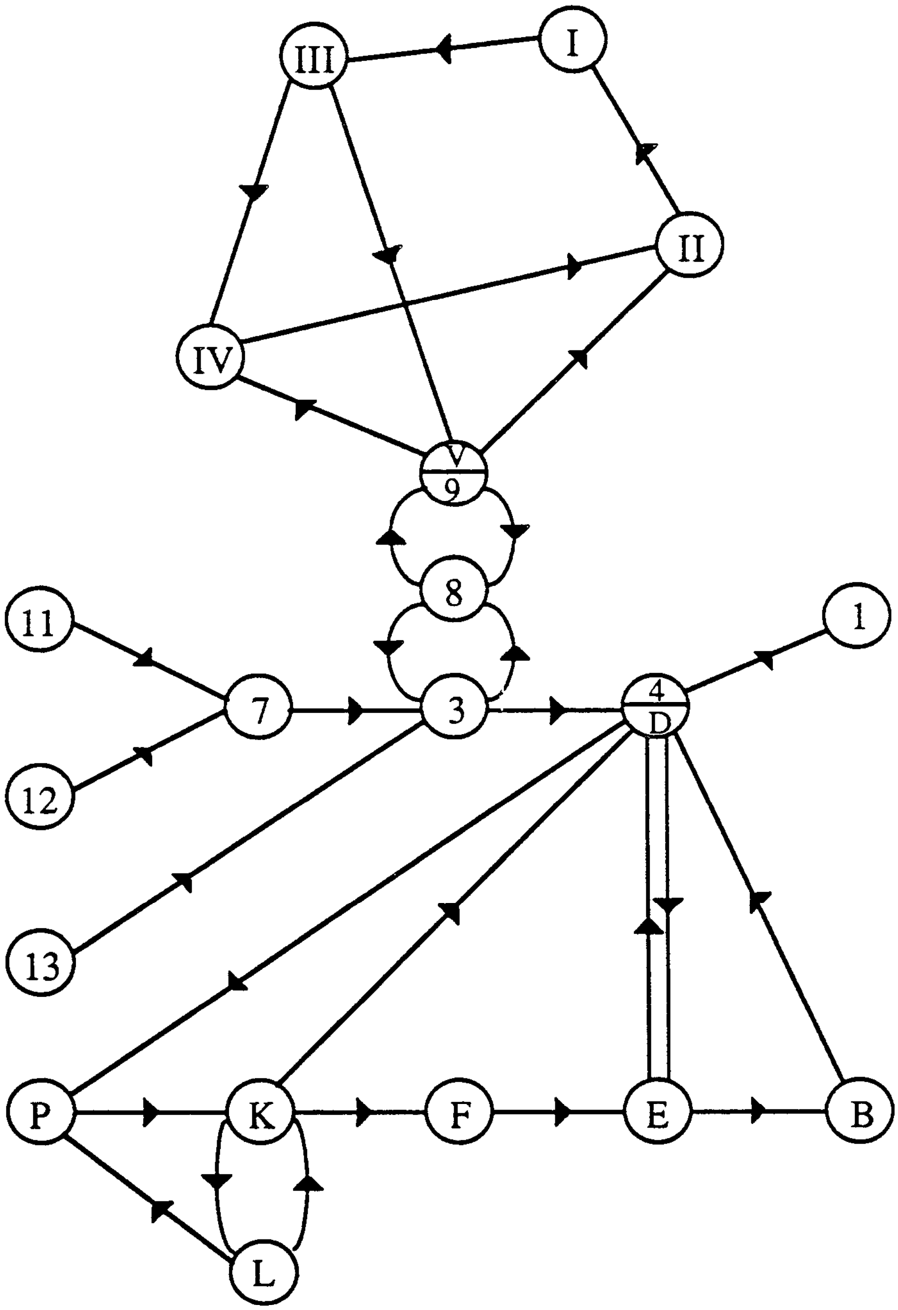


Figure 19. Convergence of Balanced. Unidirectional, and Centralized System



centralized system. As a system, the flows come into the central node, D, and back out. In Figure 19, V and 9 are the same node as is 4 and D.

In terms of GSA. the system being investigated is the internal system, and the environment outside the system is the external system. If the system of interest in Figure 19 is the "Roman" system, the "Arabic" and "English" systems are external because they are outside the system of interest. There would only be interest in the inputs from and outputs to 8 because that is the entry to the external system. The external system would be "black-boxed" with no interest in its detail. The only interest in the external system is the impact of the "Roman" system on the inputs and outputs. If all three systems are in the original matrix in order to give an initial broad understanding, the matrix can be partitioned and disaggregated down to the Roman system. Then the other systems, except for node 8, would be dropped out of the digraph. If, on the other hand, the study started with only the "Roman" system, the matrix could be expanded to include the systems connected to 8.

If we assume that the "Roman" system is an ecosystem: that the "Arabic" system is a one-directional economic production system concerned about delivering goods to 4D for distribution to a group of consumers represented by node 1; and that the "English" system is a modern governmental system which distributes goods and services to groups and collects taxes from groups: then we can begin to understand some current ecological problems. Industry 8 delivers technological processes to nature and extracts natural resources from the ecosystem at V9. In turn, processing industry 3 pays dollars for the extracted resource. It should be noted that there is no information or requirement connection between 8 and I to relate (cause 8 to internalize) to the indirect pollution impact to I. or impact on I's carrying capacity and ability to regenerate. In turn, the decision to buy from 8 by 3, and agreement to a price by 3. does not reflect ecosystem impacts.

The government, 4D, is also disconnected from the ecosystem in a direct sense. Its connection is limited to an indirect one of buying from industry 3. Its payment of a market price thus does not relate to impacts on the ecosystem. The consuming group, 1. to which the government is delivering the product is not made aware of the ecosystem. Likewise, taxpayer groups K, E, and B are not making ecological calculations or decisions when they are paying their taxes.

3. <u>Nonisomornhic</u>

The SFM conforms to the GSA standard that systems are not the isomorphic sum or reflection of the elements. As illustrated in the example just presented, it is clear that the system is not a reflection of the mining industry, and that taxpayers are not aware of ecological entities, nor are the system deliveries somehow the sum of decisions of the human agents.

The matrix and digraph of the SFM approach also allow for disaggregation into subsystems in a manner that the subsystems can be brought back together into the SFM. Because the investigators know the deliveries of the subsystem into the overall matrix before partitioning the matrix, subsystem investigators can structure analysis so that those deliveries continue to be emphasized and are available for relinking the subsystem to the matrix.

4. Equifinality

With the SFM digraph, it is possible to observe the alternative paths through which a system is achieving the same result. This diversity of means leads to system redundancy, which protects the system if one means becomes damaged or if the flow becomes slowed or disrupted.

Several different boolean algebra manipulations can be performed on the matrix and digraph to help determine alternative restoration scenarios in the case of natural resource damage. The boolean manipulations are to determine redundancy and transitiveness, and to optimize policies. It is possible to determine, with the use of the boolean matrices, how many different paths (redundancy) there are to accomplish the same deliveries or sequence of deliveries. The computer request can be made to indicate all like paths or a request can be made to identify all of a particular kind of path sequence.

In addition to redundancy, it is possible to generate alternative paths which the investigators may want to consider researching. There are, of course, potential dangers in attempting to generate real world solutions through machine logic or mathematical manipulation. Therefore, a note of caution is in order; transitivity manipulations are only completed in order to generate potential paths that might not otherwise be discovered. The skeleton matrix can be used to generate a boolean reachability matrix in order to generate all the transitivity paths which do not correctly exist in the system. Transitivity is the condition where if element A reaches B with a delivery, and B reaches C, then A is required to reach C with a delivery. A transitive system will demonstrate a chain of paths to fulfill the conditions of transitivity. The transitive paths may be utilized in two ways. First, to determine if there are real world paths that have been overlooked and, second, to represent potential policy paths that are relevant for building new deliveries.

As with transitivity, optimality paths can also be computer generated with boolean matrices. Optimality paths indicate the paths to shorten the distance through the digraph network. Again, these paths are generated to determine if there are alternative delivery paths to be considered, not necessarily to be implemented.